POTENTIAL FOR UTILISATION OF BIOMASS GASIFIER SYSTEM IN PLANTATION AND RELATED INDUSTRIES

Phase-I of the project (No. 203/01/6/89-BM)
Design, fabrication and testing of a complete drier
system for some cash crops using biomass gasifier

Submitted to

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January 1992

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PREAMBLE

A proposal was submitted to Department of Non-conventional Energy Sources (DNES) in 1989 for Design, Fabrication and Testing of a Complete Dryer System for Some Cash Crops using Biomass Gasifier, but DNES wanted to have an idea of the potential for such systems in various plantation estates and sanctioned Rs. 60,000 for a detailed study as a Phase - I of the project. In order to access the potential for gasification technology for various cash crops and to study the individual requirements of different cash crops and plantation based industries, several visits to various estates and processing units had been undertaken (See Annexure I). This report is a result of such study. Specific projects have been outlined in Annexure II for consideration both by the industries and DNES. This report is a result of such study after extensive touring of various plantation estates and related industries.

1. INTRODUCTION

Plantation crops, or cash crops as commonly known, include cardamom, tea, tobacco, rubber, pepper, coffee, cashewnut, arecanut etc. The growth and processing of these crops is largely concentrated in South India. Also, vast tracts of land in the North-East are under tea cultivation. The operations in these estates are highly labour intensive. Energy in the form of both heat and electricity is needed for processing, the thermal energy requirements being far greater than the electrical energy requirements. While the north-eastern estates depend predominantly on coal for process heat, the units in south depend on biomass, which includes firewood, coffee husk, cashewnut shells etc. Due to the uncertainty of electricity supply from the grid, the plantation industry relies heavily on diesel gensets. While biomass residues such as coffee husk, cashew shell cake etc. are obtained as by-products of the process itself, firewood needed for processing crops such as tea and cardamom is grown captively. Other fuels such as 'Leco' (briquetted lignite fines) are also used occasionally.

In spite of increasing volume of production, there have not been much changes in the technology of processing these crops. Old methods of curing (drying), which are extremely inefficient from energy point of view, still prevail in many small estates, resulting in a huge wastage of firewood. The larger and better organized companies like Tata Tea Ltd. have definitely achieved better energy efficiencies, but there seems to be significant scope for further improvement. The introduction of gasification technology in the plantation and related industries seems both desirable and plausible on account of the following points.

(i) gasification offers a better scope for utilizing biomass more efficiently

(ii) the equipment for gasification is more compact compared to the existing combustion equipment for biomass

(iii) gasification offers scope for providing both process heat and electricity

(iv) diesel consumption can be reduced greatly or even eliminated completely with introduction of gasifier based gas turbines, for example.

However, there seem to be several pre-conditions for effective introduction of the gasification technology in the plantation industry, the first and foremost being the development of a technology package tailored for use in the industry. In order to asses the potential for inducting gasification technology and to study the individual requirements of different plantation based industries, several visits to various estates and processing units had been undertaken and discussions held with technical personnel manning the units. The list of research institutes, plantation estates/curing houses and related industries visited during the course of study is enclosed in Annexure I.

This report summarizes the findings of the studies. In the following section, a cash crop-wise description of the various operations is presented, along with possible alternatives incorporating gasification. Finally, specific projects, in collaboration with specific industries, have been outlined in Annexure II for consideration both by the industries and DNES.

2. CARDAMOM

Cardamom (Elettaria Cardamomum Maton) known as 'Queen of Spices" is a native of Southern Western mountains of the Indian peninsula. The cardamom belongs to the natural order of the Scitamine and the family of Zingiberaceae to which ginger and turmeric also belong [1]. Cardamom is grown abundantly in the lush green forests of Western ghats touching the states of Kerala, Karnataka and Tamil Nadu. The crop is concentrated in Idukki, Palghat and Kozhikode districts of Kerala; Coorge, Hassan and Chikamagalur districts of Karnataka; Madurai, Tirunelveli and Coimbatore districts of Tamil Nadu. At present Kerala occupies 60% of the estimated area and 74% of production of cardamom in India [2]. The current world production of cardamom is estimated to be about 7,700 M.T., shared by India (57%), Guatemala (33%), Tanzania (6%) and Sri Lanka (4%) [1]. Figure 2.1 shows India's production and export earnings from cardamom. Another variety of cardamom known as Ammomum Subalatum or large cardamom is cultivated in Sikkim, West Bengal and Assam in the Himalayan and sub-himalayan regions.

Cardamom is mainly a small farmer's business having 84% of planters with less than 4 ha. of land but 5% of planters own 41% of the total area (Table 2.1). Thus these plantations are dominated by small farmers in number and by large farmers in area. Productive plantations range in size from small areas well under 0.5 ha. to very large estates of over 200 ha. [3].

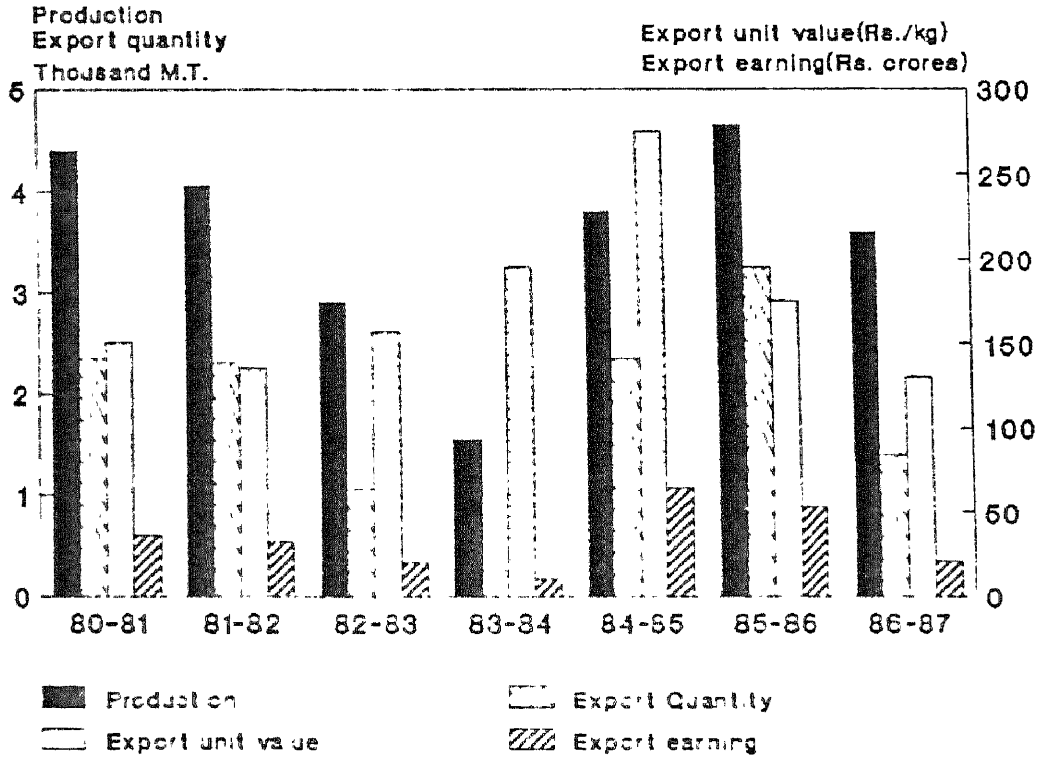

Fig. 2.1 India's production and export of cardamom

Table 2.1 Cardamom estates - analysis by size

Size of holding ha.	Number of estates	Total No %	Area ha.	Total hectarage %
0-2	17,190	65.9	16,104	19.4
2-4	4,717	18.1	13,029	15.4
4-8	2,612	10.0	14,135	17.0
8-12	1,114	4.3	13,023	15.7
12-40	252	1.0	6,248	7.8
40-80	117	0.4	6,711	8.1
80-200	67	0.3	8,211	9.9
above 200	12	+	5,323	6.4
Total	26,081	100.0	82,964	100.0

+ Less than 0.1 per cent

The cardamom picking season generally begins in the month of August and extends upto January to March depending upon rains. In the picking season 5 to 6 rounds of plucking will be done. The amount of collection in each round increases and peaks at the middle of the season and declines at the end. Each round of picking will continue for 2 to 3 weeks with an interval of 2 to 3 weeks between successive rounds which generally depend upon climatic conditions.

Cardamom Curing

Fresh cardamom has a moisture content of about 80% (w.b.) which has to be reduced to about 10% (w.b.). The fresh green cardamom must be properly dried in order to bring out the aromatic flavour and for longer preservation.

Sundrying is not allowed as it bleaches the green colour of cardamom which is economically appealing. The quality of the cured cardamom is determined by its green colour and size, which varies from 8.5 mm bold variety to 4 mm pan variety. This colour will be retained only with proper curing while driving out the moisture. While driving out the moisture care should be taken to remove moist air which otherwise bleaches the colour of capsule resulting in faded green or yellow colour cardamom and to control rate of moisture removal during initial stage of drying which otherwise results in bubbling of capsules resulting in blackish yellow capsule and splitting of the skin. For this purpose, cardamom is loaded on wiremesh racks inside the curing chamber when the temperature is at around 35-38°C. Then it is slowly increased to 42-45°C during first 7-8 hours. During this period ventilators are kept open to drive out the moist air. In some large curing chambers exhaust fans are fitted in the roof to drive out the moisture during first 7-8 hours. Afterwards ventilators are closed and temperature is slowly raised to 50-55°C and maintained at that level for next 10-15 hours. During last 5-6 hours the temperature is raised to 58-60°C to ensure that moisture content is brought down within desired level of 8-10% (w.b.). Total time required for curing of cardamom varies from 20-24 hours in case of curing chambers fitted with exhaust fan to 30-36 hours in case of old curing chambers without exhaust fans.

Cardamom Stores

The majority of the cardamom is still cured by a time old and inefficient process in cardamom curing chamber locally called as "Cardamom Stores". The general operating principle of this curing chamber is that of space heating with a heat exchanger. Hot flue gas, obtained by the combustion of the fuel wood with air in an oven, is passed through metal pipes, laid inside the curing chamber and air surrounding the flue pipe gets heated up and rises to the top of the curing chamber by natural convection (See Fig. 2.2). The fresh cardamom is spread in mono-layer on wire mesh racks inside the curing chambers. After doing thermal analysis of the heat exchanger (flue pipe type) it is observed that the conventional cardamom curing chambers operate with very low overall efficiency of about 3-8% [4]. The design and dimensions of these curing chambers have wide variations. There are two categories of the cardamom stores in operation.

The first type (fuel efficiency 2% and below) consists of a single room without any upper storey (See Fig. 2.3) [4]. The oven is usually kept outside the chamber and the hot flue gas pipe from the oven (See Fig. 2.4) passes through the room and then outside. There is no provision to remove the moist air. At the end of the 2nd or 3rd hour of curing operation, the windows are opened to remove the excess moisture. The chamber contains no insulation.

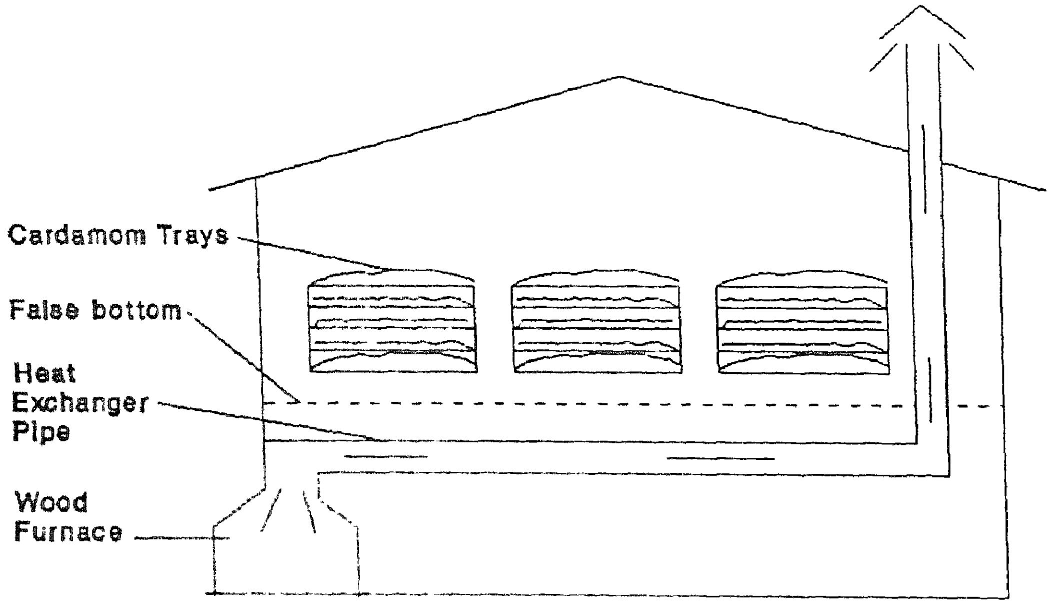

Fig. 2.2 Schematic diagram of cardamom curing chamber

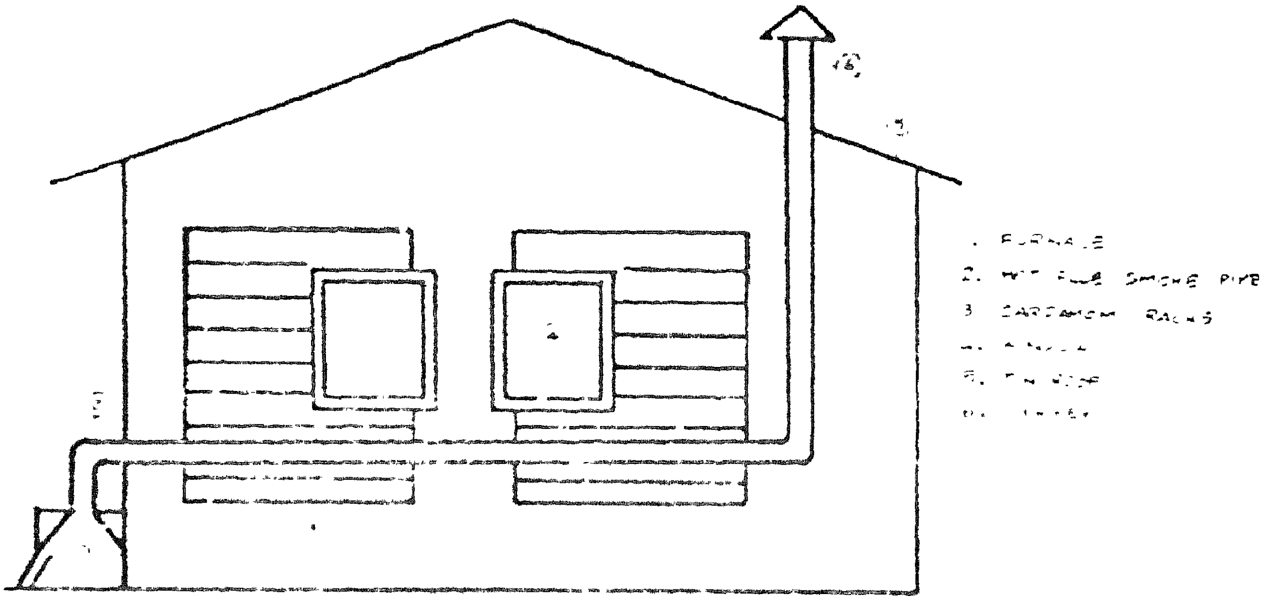

Fig. 2.3 First generation cardamom curing chamber

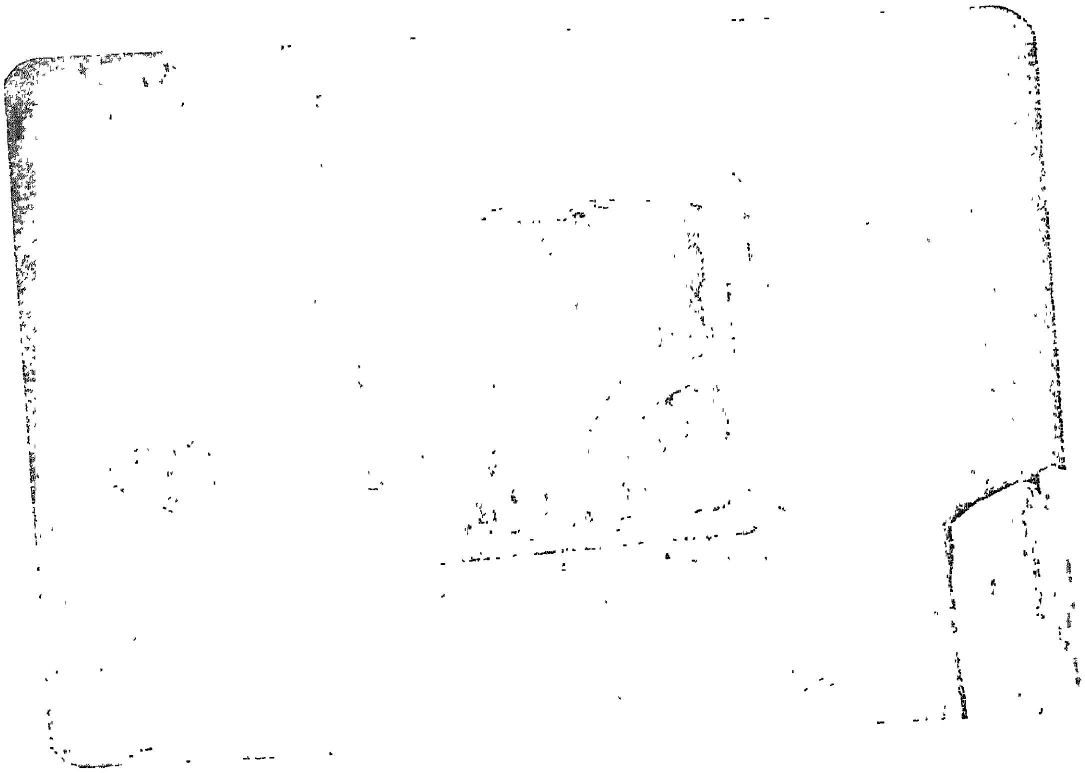

Fig. 2.4 Furnace of conventional cardamom curing chamber

The second type of curing chamber consists of a ground floor where oven (in some cases outside) and display of hot flue gas pipe are situated and one or two upper storeys in which cardamom are spread in mono-layer on the ground (See Fig. 2.5), formed by wooden rafter and wire mesh, and vertical wire mesh racks (See Fig. 2.6). The opening of windows after 2nd or 3rd hour to remove moisture is adopted. Most of the existing curing chambers fall under this category (fuel efficiency 3-8%). In some curing chambers exhaust fan is provided at the top to remove moist air during initial period of drying.

Energy Scenario in Cardamom Curing

In the hilly regions such as Kumuli hills in Kerala where production of cardamom is a major activity, the availability of coal and electricity is a severe problem. Since the cost of coal at the site is very high and electricity supply is not regular, all the planters are using firewood as a source of energy for drying of cardamom. Around 3-4 kg of firewood is required to dry 1 kg of green cardamom. On an average 0.23 to 0.25 kg of cured capsules are obtained from 1 kg of green cardamom. Since the conventional cardamom curing chambers operate at very low thermal efficiency large quantity of firewood, approximately 60,000 tons [4], is wasted every year. Nowadays planters are facing severe shortage of firewood due to fast depletion of forests and due to forest conservation acts imposed by the Government. A field survey of plantations showed that the

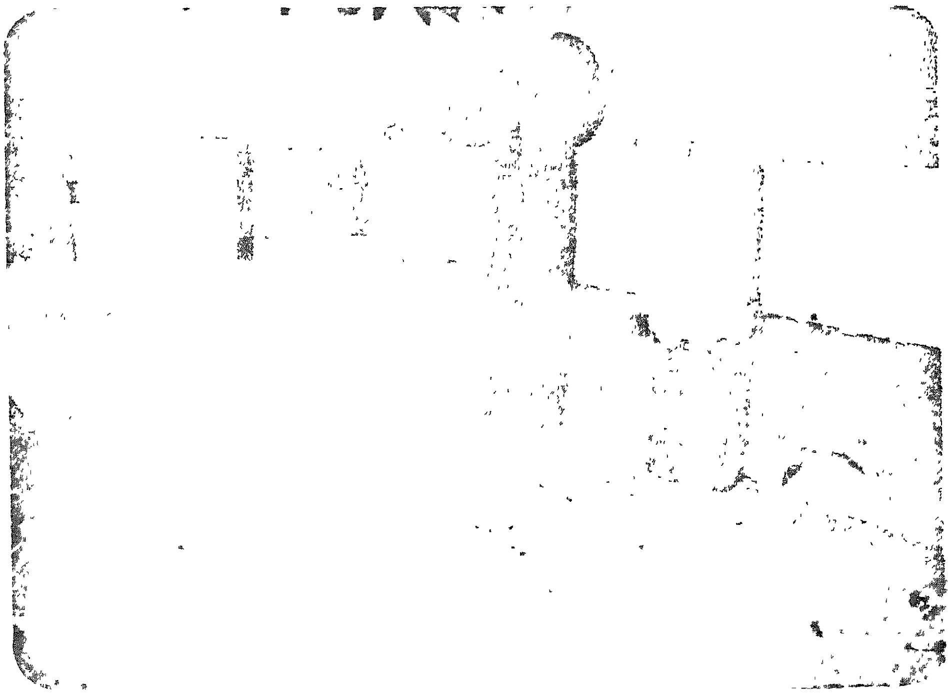

Fig. 2.5 Cardamom spread on wiremesh floor

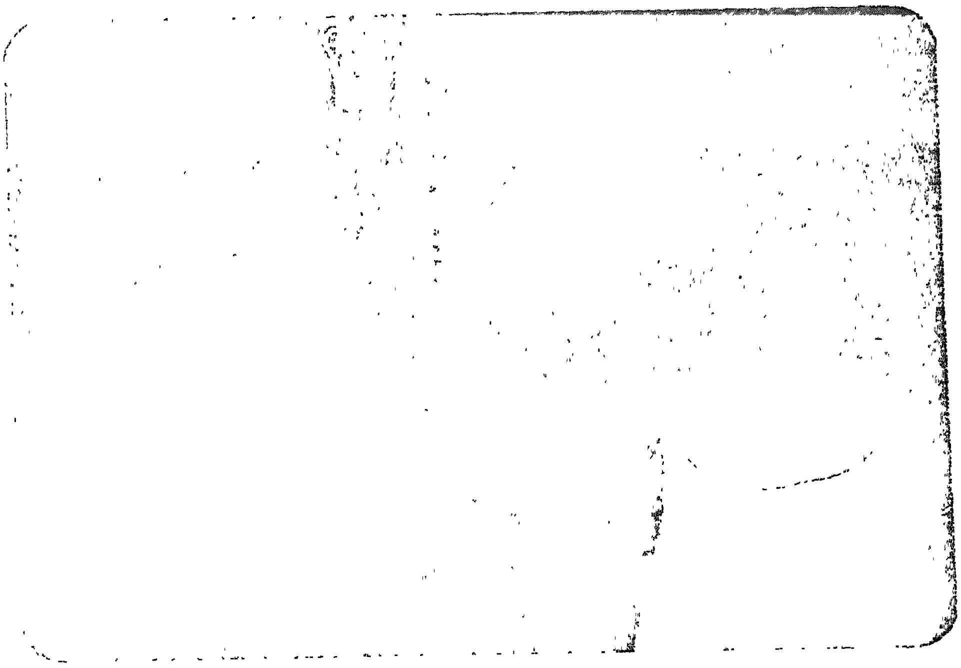

Fig. 2.6 Cardamom spread on wiremesh racks

planters are becoming aware of the fact regarding the shortage of firewood and hence they feel that there is a need to develop fuel efficient drying systems.

Many research institutes such as Regional Research Laboratory (RRL), Central Plantation Crop Research Institute (CPCRI), Indian Cardamom Research Institute (ICRI) etc. have developed different cardamom dryers. These were tested at ICRI, Myladumpara in order to have preliminary data on their performance for further modifications. The details of the tests carried out by ICRI are given in Table 2.2 [5].

Table 2.2: Performance data of the various cardamom dryers tested

Name of the dryer	Capacity in kg	No of trials carried out	Temperature maintained (°C)	Qty. of dry cardamom (kg) mean	Percentage recovery	Drying time (mean) hrs.	Fuel type	Qty used (kg)	Colour of dried capsules
1. Low cost dryer (CPCRI)	30	2	40-55	5.150	17.17	32	Firewood	31	Faded green
2. MELCAARE	120	2	40-60	23.375	19.48	26	- do -	215	Green
3. Electrical dryer (RRL)	55 (chemically treated)	2	45-50	10.850	19.73	22	Electricity	18.5* units/hour	Green
4. Electrical dryer ([illegible])	30	3	45-50	Could not complete due to power failure					

* [illegible]

From the observation of these performance test data on different cardamom dryers it can be concluded that there is still lot of scope for improving thermal efficiency and reducing drying time in a cardamom curing process.

Technological Options for Improvement

Here various options for improving the cardamom curing system to reduce fuel consumption or drying time or both are discussed.

Modifying Existing Curing Chambers

The conventional cardamom curing chamber is a big room through which flue pipes are laid down for air heating. This is a huge structure and the planters may be reluctant to switch over to a completely new drying system. Therefore, if efforts are directed towards the improvement of conventional curing chambers, many planters may come forward to implement them in order to improve the efficiency of the existing curing chamber. This approach may gain wider acceptability among planters since existing curing chambers can be used as they are.

In order to improve the efficiency of the curing chamber, the following options can be considered.

(i) Providing black paint on the flue pipe to improve the heat radiated by the flue pipe.

(ii) Providing fins on the flue pipe in order to increase the heat transfer area.

(iii) To provide insulation to the walls to prevent loss of heat through it. Providing insulation inside may be more effective since the absorption of heat by the walls would then be lower.

(iv) Providing radiation shield between flue pipe and wall structure. This may help in utilising radiant heat tc heat the air rather than wasting it if it falls on the wall structure where it will get absorbed and will not be given back to air.

(v) Providing small annulus type structure around flue pipe and circulating room air over the flue pipe through the annulus with the help of small blower which may increase the heat transfer coefficient on air side.

Though all these options improve the heat transfer the options (iii) to (v) seem to be more effective since these improve the heat gained by the air rather than just throwing out more heat from the flue pipe. Of course all these options have to be tested for their relative effectiveness.

Improving Efficiency of Heat Exchanger and using Forced Air Flow Method for Cardamom Curing

As discussed earlier the conventional cardamom curing chamber operates on principle of space heating. The heat is transferred from flue gases to room air by natural convection, and for air the heat transfer coefficient values are generally low. So the best method is to go for a cabinet tray dryer in which cardamom capsules are spread on wiremesh racks in mono-layer and hot air is blown to remove moisture from the capsules.

In an earlier, TERI funded investigation it was observed that for maintaining green colour of the capsules and at the same time avoiding splitting/breaking of skin the hot air velocity over the capsules should be around 0.5 m/sec at temperature of about 50°C [4] In order to develop an energy efficient dryer for cardamom, TERI has developed simple but energy efficient compact plate-fin type cross flow heat exchanger with effectiveness of around 70% which resulted in combined furnace and heat exchanger efficiency of about 45-50%. This prototype, developed in a DST funded project, was field tested in Kerala during the last cardamom harvesting season successfully. During the field testing drying time of the order of 14-15 hrs and combined (furnace and heat exchanger) efficiency of the order of 40-50% was achieved [6]. Photographs shown in Figs. 2.7 and 2.8 show complete view of drying system from furnace side and its side view respectively. Thus by introducing highly efficient compact plate-fin type heat exchanger and using forced flow method substantial fuel saving can be achieved.

Scope for Utilising Biomass Gasifier Systems for Curing of Cardamom

In the gasifier system the fuel in the form of chopped firewood or any other biomass (either in loose or briquetted form) is gasified, i.e. burned under controlled insufficient air supply, to obtain producer gas. This combustible gas produced in the gasifier undergoes the process of cleaning and cooling, to remove tar and dust content to an acceptable level. This gas is then burned with sufficient amount of excess air in a burner to obtain the required temperature and the resulting hot air-gas mixture can be directly used for drying. Thus the gasifier system can, in principle eliminate the heat exchanger in the conventional system.

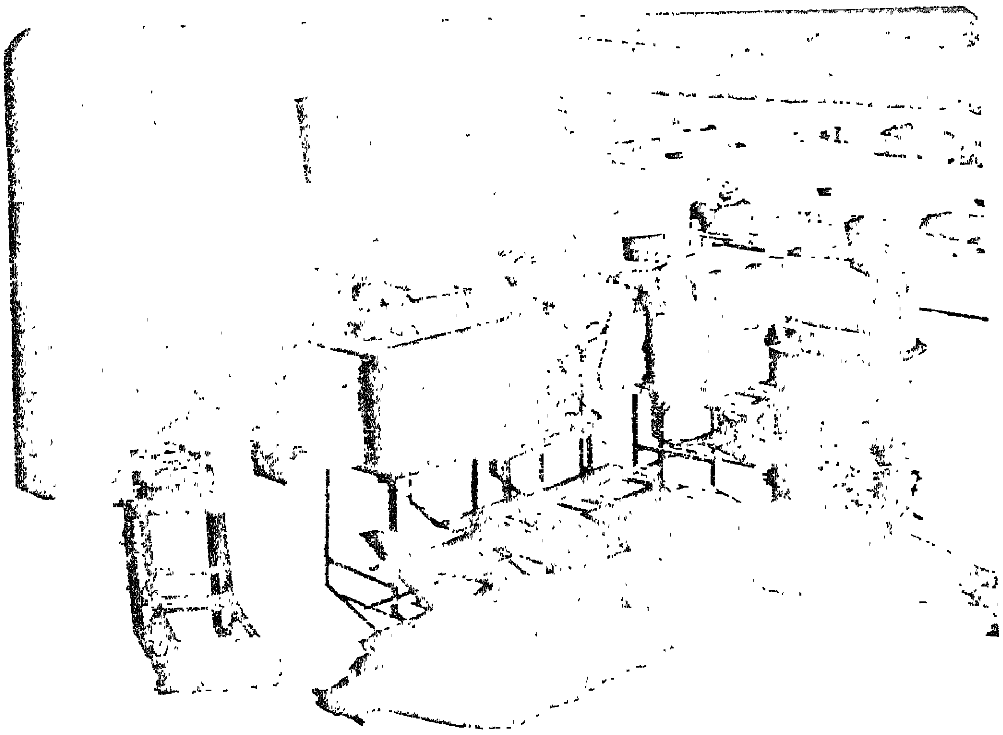

Fig. 2.7 Overall view of the system from furnace side

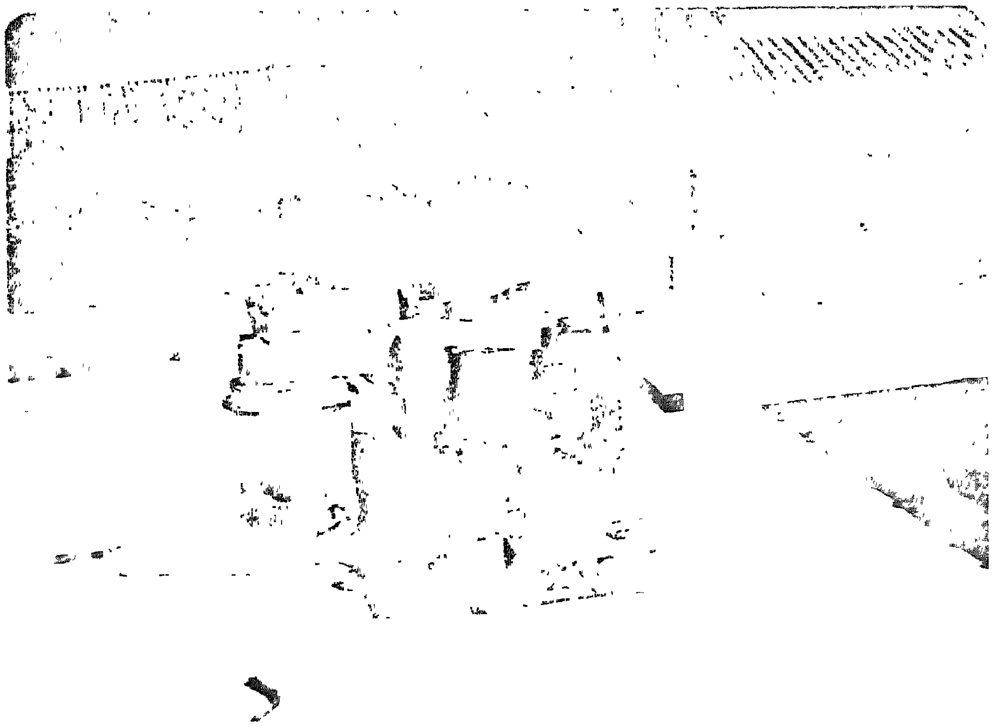

Fig. 2.8 Side view of the complete drying system

Power cut is a regular phenomenon in hilly areas of the Nilgiris where majority of tea factories and other plantation estates are located. So the industry has to go for diesel generator sets for regular power supply. Gasifier application can also be extended for power generation making the complete system independent without relying on the main commercial source of energy such as coal and electricity. For this purpose the diesel engine of the generator is operated in dual fuel mode (i.e. both diesel and producer gas are supplied to engine) resulting in about 65-70% diesel replacement thus needing only 30-35% diesel.

Figure 2.9 shows the flow diagram of the biomass gasifier system which can be used for drying or power generation or both simultaneously. Since heat exchanger is absent in the gasifier-based drying system the overall efficiency of the drying process will be obviously higher than the present drying system resulting in large fuel savings. The system application is extendable to power generation which gives about 65-70% diesel replacement in diesel generators, thus saving large amounts of diesel. Thus biomass gasifier based drying systems can give benefit and so return of the investment incurred in it by two ways:

(a) Fuel wood saving in drying process

(b) Diesel saving in power generation.

For a typical cardamom curing chamber having capacity to cure 400 kg of fresh cardamom, a sample calculation for determining the gasifier capacity in terms for wood consumption and gas production rate is given below:

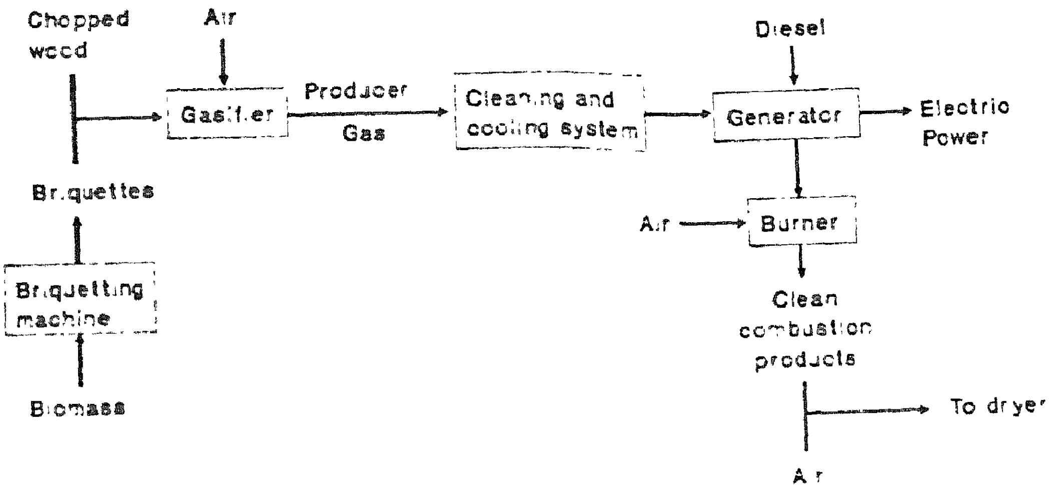

Fig. 2.9 Biomass gasifier based drying / power generating system

Capacity of curing chamber (kg green cardamom W) = 400 kg

Initial moisture content (MI) = 80% (w.b.)

Final moisture content (MF) = 10% (w.b.)

Drying time (Td) = 15 hrs.

Hot air temperature (Th_a) = 55^oC

Cold air temperature (Tc_a) = 15^oC

Calorific value of producer gas (CVF) = 1100 kcal/Nm^3

The theoretical amount of hot air required can be calculated as:

$$ma = \frac{W\ (MI - MF)}{(1 - MF)\ (WF - WI)\ Td}$$

$$= 3190.88\ kg/hr$$

where WI and WF is specific humidity of air at inlet and outlet of dryer respectively.

Producer gas required for drying with burner efficiency (η_b) of 90% is

$$= \frac{ma\ C_p\ (Th_a - Tc_a)}{CVF\ \eta_b}$$

$$= 30.94\ Nm^3/hr$$

For large curing chambers used for curing of tobacco leaves, which are similar to cardamom curing chambers in construction and also operate on principle of space heating using flue pipe, heat losses due to ventilation, conduction through wall structure are reported to be in the range of 16-20 and 14-18% respectively amounting to total loss of about

34% [7]. Therefore, after accounting for these losses the amount of producer gas required for drying will be:

$$= 46.88 \text{ Nm}^3/\text{hr}$$

For operating blowers for handling air and gas as well as for other electrical needs at cardamom store the total electricity required can be assumed as 10 kW.

Amount of diesel required to operate 10 kW diesel genset

$= 0.29$ (lit/kWh) x 10 (kW)

$= 2.90$ lit/hr

$= 2.465$ kg/hr

Approximately 65% of diesel replacement can be achieved when genset is operated on dual fuel mode.

Therefore amount of gas required for power generation

$$= \frac{0.65 \times 2.465 \times \text{calorific value of diesel}}{\text{Calorific value of gas}}$$

$$= \frac{0.65 \times 2.465 \times 10500}{1100}$$

$$= 15.30 \text{ Nm}^3/\text{hr}$$

Total amount of gas required for cardamom drying

$= 46.88 + 15.30$

$= 62.18 \text{ Nm}^3/\text{hr}$

Specific gasification rate for wood = 2.3 Nm^3/kg

$$\text{Therefore wood consumption rate} = \frac{62.18}{2.3}$$

$$= 27.03 \text{ kg/hr}$$

Total wood consumption per batch $= 27.03 \times 15$

$= 405.45$ kg

Therefore specific fuel consumption (kg/kg of green cardamom) $= \dfrac{405.45}{400}$

$= 1.01$ kg/kg

Thus using biomass gasifier based drying system specific fuel consumption can be brought down from the present level of 3-4 kg to about 1 kg per kg of green cardamom.

3. CASHEW

Cashew cultivation is an important horticultural activity in India. Cashew (Anacardium occi-dentale) was introduced in India by early Portugese settlers in the 16th century. It later spread as a dry land crop in Kerala, Karnataka and Goa. After independence, cashew cultivation has caught the fancy of agriculturists in Maharashtra, Tamil Nadu, Andhra Pradesh, Orissa and, to some extent, in West Bengal and Tripura.

In 1989, the total harvest of raw cashewnuts exceeded 2.5 lakh tonnes in the country. This has resulted in a record export of 44,857 tonnes of kernels, valued at Rs. 360.34 crores. Figure 3.1 shows quantity and earnings from export of cashew from India [8].

The cashew industry in India comprises units in the tiny sector and in the small sector. It has a total installed capacity exceeding six lakh tonnes per annum. It is mainly concentrated in Quilon district and some other places in Kerala, South Kanara in Karnataka, Goa, Sindhdurg and Rantnagiri districts in Maharashtra, Kanyakumari and South Arcot districts in Tamil Nadu and Srikakulam district in Andhra Pradesh.

Cashewnut manufacturing process

Cashewnuts, after collection from the trees undergo processing in order to get the finished product, or to extract cashew oil, which is a versatile chemical input for

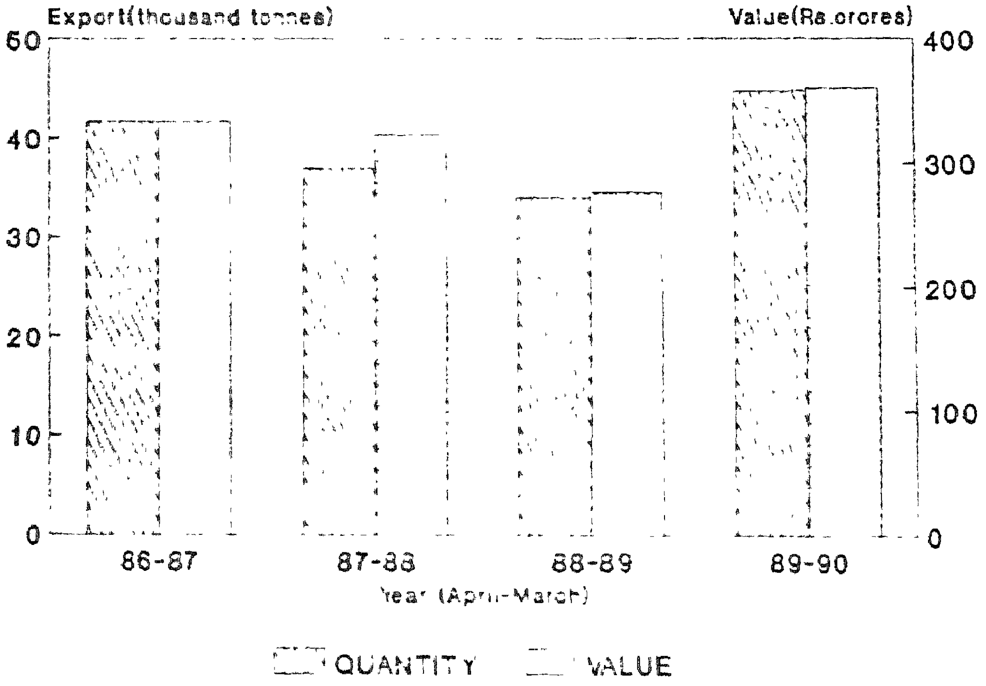

Fig. 3.1 Cashew Export from India

use in the friction-dust, paints and varnishes, foundry chemicals and resin industry. Cashew processing consists of following stages:

(a) Drying and Storing

(b) Roasting

(c) Shelling

(d) Hot (Drying) Chamber (Borma)

(e) Peeling

(f) Grading

(g) Packing

(a) Drying and Storing

The raw cashewnuts purchased from the market normally have moisture. To remove the moisture content, they are to be sun dried in an open yard. After drying, they are stored in bags of 75 kgs. For keeping good quality and for yielding good quality kernel, it is essential that the nuts are dried, though no specific optimum moisture content has been arrived at. With a good drying, they not only stand well, but also give a fairly good product.

(b) Roasting

Roasting involves application of heat to the raw nuts in order to release the liquid in the 'Pericarp', so that the shell becomes brittle and facilitates the extraction of kernel.

In practice, four different methods of roasting are followed:

(i) Drum Roasting

In this process, the nuts are fed into a rotating drum, which is heated initially to red hot, sufficiently to allow the shell portion of the nut to ignite and burn (See Fig. 3.2). Once ignition starts, no further heating is necessary and the drum maintains the temperature of its own because of the burning of oil oozing out of the nuts. The temperature of the drum is fairly high. It is stated that in this method of roasting, the shell becomes very brittle and the rate of shelling and the out-turn of whole kernel is higher compared to other methods. The roasting generally takes about 3-5 minutes and the drum is rotated by hand. The roasted nuts which are still burning are removed from the discharge end and immediately covered by ash to absorb the oil that is found on the surface. The chief disadvantage of this method of roasting is the total loss of shell liquid, which has a good commercial value nowadays.

(ii) Oil Bath Roasting

In this process, the nuts after conditioning are allowed to pass through a bath of heated cashew shell liquid maintained at a temperature of approximately 350-450^{O}F for about 1-2 minutes. The roaster consists of a rectangular vessel with or without a semi-circular bottom, in which there is either a screw or belt conveyor, operating inside the bath of liquid. The vessel is embedded in brick work and heated by a furnace in which spent shell is used as fuel. By adjusting the speed of the conveyor it is possible to adjust

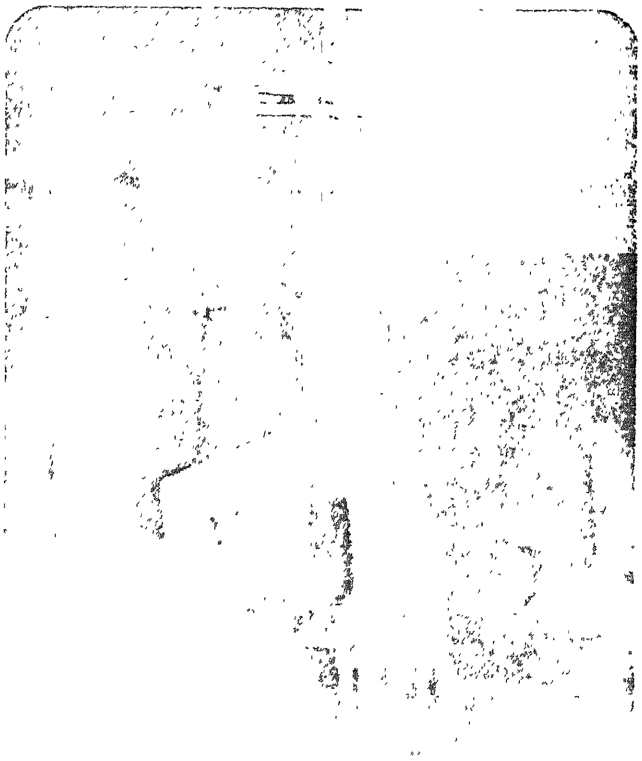

Fig. 3.2 Cashew drum roaster

the roasting time. It is estimated that more than 50-60% of the shell liquid is released by this means. The nuts are then conveyed through a suitable outlet to a centrifuge, where the residual oil adhering to the surface of the shell is removed by centrifuging. The nuts are then mixed with ash and sent for shelling. The oil overflowing from the roaster and the oil recovered in the centrifuges are both conveyed to tank for being filled into drums.

(iii) Mild Roasting

The nuts after conditioning are given a mild roasting in equipment at comparatively low temperatures for 20-25 minutes to remove the surface water but not sufficient to bring out the shell liquid. It is said that this process loosens the kernels inside and makes it easy for cutting and removal of kernel. The nuts after roasting are spread on floor in a thin layer for cooling for 24 hours and later they are sent for shelling.

(iv) Steam Roasting

Steam roasting process is now gaining importance in view of the fact that the quality of the cashewnuts is comparatively better and this process requires less labour. It is possible to have better control over the process. Sun dried cashewnuts are put into steam and roasting is carried out for a fixed time. The nuts after roasting are spread on floor in a thin layer for cooling for about 24 hours and later they are sent for shelling.

(c) Shelling

Shelling refers to breaking down of the nut and removing shells. The roasted cashewnuts are cut on the cutters to break open and remove the shells. About 5% of cashewnuts produced in India, principally in Tanjore and South Arcot Districts of Tamil Nadu are simply dried in the sun for 2-3 days and shelled without roasting. Now many factories in Mangalore are using a hand operated deshelling machine which are manufactured locally. This machine is similar to a shear used for supari (arecanut). With the help of this machine it is possible to shell approximately 50 to 55 lbs of nut in an 8 hour day.

(d) Hot (Drying) Chamber (Borma)

As the shelled kernel has a moisture content and is susceptible to fungal attack, drying is to be done immediately. Besides, to facilitate removal of Testa (Red skin), the shelled kernel is heated in a hot chamber (Borma). This shrinks the kernel so that the testa is loosely adhering to it and can be removed by hand. For this purpose most of the factories adopted a tray drier, commonly known as Borma (See Fig. 3.3). They are chambers which are indirectly heated on three sides by means of flue gases from furnace at the bottom where the shells are burnt. The temperature maintained inside the Borma is of the order of 80-90^{o}C. The kernels are kept in Borma for periods varying from 3-7 hours and are sometimes interchanged, since there is no uniform heating in all sections of the Borma. After the kernels are

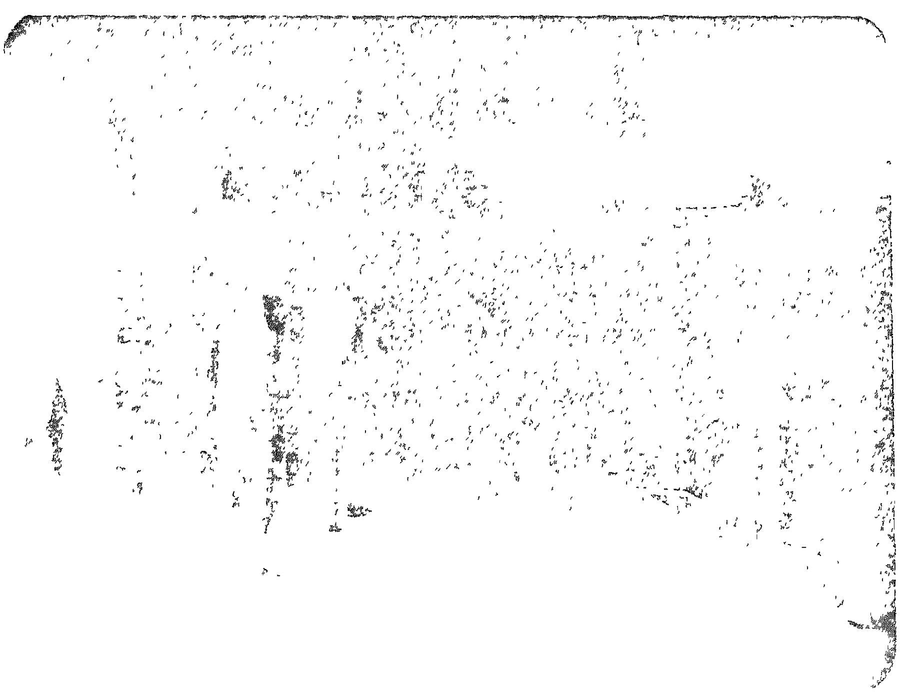

Fig. 3.3 Cashew heating in 'Borma'

heated sufficiently, they are removed from the Borma and heaped in covered metallic wares and kept such for 24-28 hours, before they are sent for peeling.

(e) Peeling

Peeling refers to the removal of Testa (Red skin) of the kernel. This is done by hand. The red skin would have become loose by drying in the Borma and the kernel is easily peeled off.

(f) Grading

After peeling the red skin, the kernels are sorted out into wholes, splits, brokens, etc. and the wholes are graded into different sizes on the basis of the number of wholes per lb., according to the specifications. A high percentage of kernels get broken into various shapes. Also many kernels get scorched or dis-coloured in the process. Therefore, grading is also done according to different sizes, shapes and colours. All these operations are done manually.

(g) Packing

Kernels graded are normally packed in 25 lbs tins (11.34 kgs.) which are filled by means of a chute into the tins kept shaken to fill uniformly. After filling and weighing, the tins are vacuumised, and filled with carbon-dioxide gas with the help of gas packing equipment known as 'Vitapack'. Immediately after removal from the 'Vitapack' lids are put on top and soldered.

Scope for Improving the Efficiency

In the processing of cashewnuts heat energy input is needed in two stages, viz. roasting (either drum/oil bath/ steam roasting) and heating in 'Borma'. Cashew shell is generally used as a fuel for providing thermal energy since it is made available during process itself. For drum roasting around 15 bags (1 bag = 45 kg of cashew shells) of shell are required for roasting 70 bags (1 bag = 80 kg of raw cashewnut) of raw cashewnuts. In case of oil bath roasting 1 kg of shell is required to roast 8 kg of raw cashewnuts. During oil roasting one bag of raw cashewnut gives out 10 kg of cashew oil. In roasting operation fuel saving can be achieved with better design of combustion chamber and by controlling the air-fuel rates.

For drying cashewnut in 'Borma' hot air at around 90-100°C is supplied. Hot flue gases obtained by combustion of cashew shell as fuel is used to heat the air going into the 'Borma' by using a shell and tube heat exchanger. In shell and tube heat exchanger, hot flue gases are passed through the tube side and air is passed on the shell side. On an average 7 kg of cashew shell is required to dry 1 kg of cashewnut in 'Borma'. For flue gas and air, the heat transfer coefficients are comparatively low requiring large heat transfer area, i.e. large size of heat exchanger. Though shell and tube type heat exchangers are simple in fabrication and are suitable for liquids for gas to gas heat transfer they generally operate at lower effectiveness. Use of simple plate-fin type compact heat exchanger (which provides large heat transfer area per unit volume and so operates at higher effectiveness) can result in substantial fuel saving. TERI, under a DST funded project had developed such a device using square profile aluminium plate-fin and successfully used it for improving efficiency of cardamom curing (See Fig. 3.4).

Scope for Utilising Gasifier Based Power Generating Systems in Cashew Industry

Standard size bag containing 80 kg of raw cashewnuts gives 35 kg of shell and 23 kg of processed nut. In all around 55,000 tonnes of raw cashewnut are processed every year. Approximately 50% of shell obtained from raw cashewnut is needed as fuel for providing thermal energy at various stages of cashewnut processing. Thus approximately 12,000 ton/year of cashew shell is available in excess in cashew industries which at present is sold outside at a nominal price of Rs. 0.30-0.35 per kg. From rough calculation it is estimated that approximately 275 lakhs units of electricity can be produced per year using this available shell. Utilising this excess shell for power generation can be an attractive option for cashew industries. Also electricity supply being based on hydro-electric power stations is not available throughout the day due to load shedding in the summer (February-June) which is the processing season for cashew.

For a typical cashew manufacturing factory sample calculations are given here to work out amount of electricity

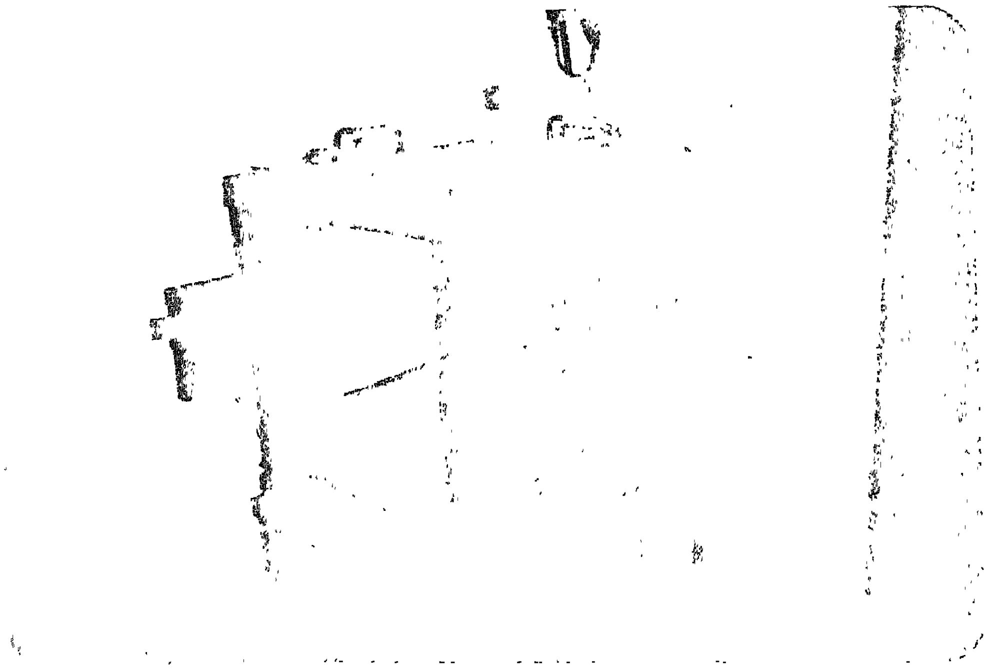

Fig. 3.4 Compact plate-fin type multi pass cross flow heat exchanger

that can be produced using diesel genset operating on dual fuel mode using diesel and producer gas obtained by gasifying cashew shell. Detailed trial runs for obtaining clean producer gas will have to be undertaken for developing the system.

Raw cashewnut processed = 8 ton/day

Excess shell available = 1.75 ton/day

Calorific value of shell = 5546.6 kcal/kg

Calorific value of Testa/skin = 4676.0 kcal/kg

Gas yield (approximately) = 2.2 Nm^3/kg

Amount of producer gas obtained = 3850 Nm^3/day

Calorific value of producer gas = 1100 kcal/Nm^3

Assumed thermal efficiency of diesel engine in dual fuel mode = 15%

Electricity available from producer gas $= \dfrac{0.15 \times 3850 \times 1100}{860}$

= 738.7 kWh/day

~ 740 kWh/day

Total saving on electricity per day, assuming Rs. 2 per unit electricity charges, will be

= 2 x 740

= Rs. 1480 per day

Cost of cashew nut shell = Rs. 0.30 per kg

= 0.30 x 1750

= Rs. 525 per day

The net saving per day will be

= Rs. 955 per day

Total capital cost of the gasifier based power generating system will be around Rs. 6 lakhs as per the following break-up:

Gasifier system for 500 Nm^3/hr capacity = 2 lacs

Diesel genset of 75 kW = 4 lacs

Total system cost = 6 lacs

If a diesel genset is already existing, the initial capital investment will be only Rs. 2 lakhs. Therefore simple pay back period in terms of operating days with an 8 hour shift will be:

$$= \frac{2 \times 10^5}{955}$$

$$= 210 \text{ operating days}$$

With approximately 150-160 operating days per year simple pay back period will be less than 2 years.

4. COFFEE

In India two varieties of coffee are grown viz. Arabica and Robusta. Both varieties of coffee are further divided into two categories viz. cherry and parchment coffee depending upon the method of processing. Cherry coffee is dried without removing the outer shell. In case of parchment coffee, firstly the top skin is removed and cherry is washed to remove pulp and then dried. Coffee is grown in South India mainly in Karnataka, Kerala and Tamil Nadu. Majority of the coffee is grown by small planters having area below 10 ha which constitutes approximately 98% of total holdings and 61% of total coffee cultivated area. Table 4.1 gives details of Indian coffee production of each variety, area under cultivation etc. [9].

Drying

Matured coffee cherry contains moisture to a level of 60-65% (w.b.) depending upon level of maturity of the cherry. After drying this has to be brought down to a standard level of 9.5% (w.b.). This is partly done at estate level and rest at the coffee curing works governed by coffee boards. Then it is sent for dehusking (hulling), grading and roasting.

The most primitive method of drying coffee is to spread it in thin layers on a concrete surface, exposed to the sunlight. This method requires low equipment costs, but labour costs are high. The coffee beans should be turned by raking them occasionally, and they are returned to a shelter at the end of each afternoon. Drying by this method requires

Table 4.1: Indian coffee at a glance

Major varieties grown : Arabica and Robusta

Traditional coffee growing States : Karnataka, Kerala and Tamil Nadu

Coffee season : October to September

Area under coffee (1987/88 season)	**Arabica**	**Robusta**	**Total**
	(in Hectares)		
STATES			
Karnataka	79,899	46,464	126,363
Kerala	3,190	65,159	68,349
Tamil Nadu	27,270	5,508	32,778
Andhra Pradesh	7,274	--	7,274
Other States	5,682	1,755	7,437
ALL INDIA	123,315	118,886	242,201

India's share in the total world Coffee (1988/89 season)

Area : 2.1 per cent
Production : 3.8 per cent

Size of holdings (31.3.1988)

Size	**No. of holdings**		**Area (Hect.)**	
Below 2 Hect.	103,821	(86.6)*	86,652	(35.8)*
Below 4 Hect.	112,607	(93.9)	112,683	(46.5)
Below 10 Hect.	117,790	(98.2)	147,845	(61.0)
Above 10 Hect.	2,150	(1.8)	94,356	(39.0)
Total	119,940	100.0	242,201	100.0

* Figures in brackets indicate percentage to total

Production : (Six yearly average ending 1989/90)		
	Arabica	78,500 Tonnes
	Robusta	77,500 Tonnes
	Total	156,000 Tonnes

Productivity per hectare : (1988)		
	Arabica	901 kgs.
	Robusta	1,078 kgs.
	Average	990 kgs.

Export earnings (1988/89) :		
	Quantity	133,361 Tonnes
	Value (Rs.)	357.86 Crores

several days, and labourers must be standing by at times to return the beans to shelter in case of rain, which occurs suddenly and frequently in the coffee region. Excess moisture leads to problems of discolouration and onion flavour Onion flavour is also liable to appear in lengthy fermentation and is an additional worry since the rain normally tends to increase fermentation time because of lower temperatures. On the other hand lesser amount of moisture or lower drying results in the liquor turning sour.

The rate of drying is a very important factor since very rapid drying of wet coffee causes severe cracking. High temperatures cause coffee to turn sour apart from causing uneven drying. Very rapid drying no doubt, cuts down the drying time but in the process the photo sensitive reactions which contribute to flavour quality are not completed. This results in brownish yellow beans. Further rapid drying causes irreversible shrinkage which in turn prevents easy movements of the moisture (from the centre) in the outward direction resulting in pale and bleached beans. Hence drying should be done at a speed which not only permits the outer layer of the bean to dry first but ensure an even temperature which enables the moisture to percolate from the inner layers of the bean to the outer layer.

Major disadvantages of conventional drying process are:

1. Higher labour costs.
2. A substantial amount of time is required for the drying process to be completed and often one is not sure about

the total time required since this would depend upon the weather conditions.

3. Total dependence on weather conditions so that even if the beans are in the final stage and there is a slight rainfall then the entire effort is wasted.
4. Large amount of space required.

So in order to overcome these disadvantages, TERI has developed a cabinet tray dryer in which coffee beans are placed in mono-layer over wiremesh trays and hot air is passed over it to remove moisture. This hot air is obtained from flue gases with the help of compact plate-fin type cross flow heat exchanger. During last coffee drying season (December-March) the prototype unit was successfully tested in Kerala for drying cardamom, pepper and coffee. For coffee to reduce moisture content from initial level of 65-70% (w.b.) to below 10% (w.b.) it took approximately 18-24 hours with combined thermal efficiency of furnace and heat exchanger of about 45-50%. The photographs in Figs. 2.7 and 2.8 shows complete assembly of the drying system.

Various Options for Utilising Available Coffee Husk in Coffee Curing Works

As mentioned earlier coffee is grown in small estates and dried partly at estate level and the remaining at coffee curing works. All the coffee curing works are governed by Coffee Board. Small farmers send their coffee to these curing works and after curing and processing coffee, Coffee Board sells it. In a single coffee curing works, such as

Mysore Coffee Curing Works, Chikamagalur, 8000 tons (4800 tons parchment coffee, 3200 tons cherry coffee) of coffee is processed per year in the plant. Processing of parchment and cherry coffee produces 20% and 50% coffee husk respectively. Husk obtained from parchment coffee can not be briquetted as there is no lignin. Cherry husk can probably be gasified directly. This has to be verified through trial runs. Since large quantity of coffee husk is available at curing works, proper utilisation of it can be made to meet electrical and process heat requirement of the curing works. Various options are:

(i) Pyrolysis/Briquetting of the Coffee Husk

One way of utilising the available loose biomass in the form of coffee husk is to change it into compact briquetted form with higher heating value. This can be achieved by pyrolysing and briquetting of coffee husk. This briquetted form of fuel can then be sold as a fuel or can be utilised in boilers or gasifier for either producing steam for process heat or for generating electricity. Cost figures for a typical fuel processing system having capacity of 3.5 to 4 tons per day (according to the quotation received by Mysore Coffee Curing Works) are:

Pyrolyser = 4.90 lacs
Blender mixer = 0.55 lacs
Briquetting extruder = 1.80 lacs
Dryer = 1.25 lacs
Total = 8.50 lacs

Details of binder to be used, overall economics of the process etc. are not available.

(ii) Generating Process Heat and Electricity Using Steam Turbines

Coffee husk can be used for producing steam which can be passed through a back pressure steam turbine for producing electricity. The exhaust steam coming out of turbine can be utilised as process heat, e.g. for obtaining hot air needed for drying, etc.. For a typical coffee curing works, for example, Mysore Coffee Curing Works, Chikmagalur, the installed capacity of generator set is around 200 kW. Assuming that the steam turbine cycle efficiency is about 15% and that the calorific value of the coffee husk is about 3000 kcal/kg the fuel consumption rate will be:

$$= \frac{200 \times 860}{0.15 \times 3000} = 382.2 \text{ kg/hr}$$

$$= 1.911 \text{ kg/kWh}$$

Price of the coffee husk at present is around Rs. 0.40 per kg. Thus the cost of electricity generated works out to be:

$$= 1.911 \times 0.40 = \text{Rs. } 0.76 \text{ per kWh}$$

Amount of coffee husk available = 2560 ton/year

Amount of electricity that can be generated annually by utilising available coffee husk

$$= \frac{2560 \times 10^3}{1.911} = 1.34 \times 10^6 \text{ kWh}$$

Approximate capital cost of the system

= Rs. 35 lacs

Annual expenditure as interest on the capital investment at the rate of 18% p.a.

= Rs. 6.30 lacs

Operational maintenance and repair cost (OMRC) at the rate of 10% p.a.

= Rs. 3.50 lacs

Annual capital cost of electricity generation

$$= \frac{6.30 + 3.50}{1.3 \times 10^6}$$

= Rs. 0.73 per kWh

Total cost of power generation

= 0.76 + 0.73

= Rs. 1.49 per kWh

Scope for Biomass Gasifier Systems in the Coffee Curing Works

Gasification of coffee husk to obtain producer gas and utilising it to run the diesel genset on dual fuel mode to replace approximately 65-70% of diesel consumed can be an attractive alternative since the existing generator set of the curing works can be used which means low initial capital investment. Here, a sample calculation is given for Mysore Coffee Curing Works to show the amount of saving that can be achieved using gasification of coffee husk.

Installed capacity of diesel genset = 200 kW

Amount of diesel consumption (0.3 lit/kWh) = 60 lit/hr

Calorific value of diesel = 10500 kcal/kg

Specific gravity of diesel = 0.85

Calorific value of producer gas obtained from gasifier (assumed) = 1100 kcal/Nm^3

Amount of producer gas needed to replace 65% of diesel when diesel genset is operated on dual fuel mode will be:

$$= \frac{0.65 \times 0.85 \times 60 \times 10500}{1100} = 316.4 \ Nm^3/hr$$

Specific gas yield (assumed) = 2.2 Nm^3/kg

Amount of coffee husk required = 143.8 kg/hr

Amount of diesel saving = 0.65 x 60

= 39 litres/hr

Price of diesel = Rs. 5 per lit.

Price of coffee husk = Rs. 0.40 per kg

Net saving due to diesel replacement by producer gas.

= cost of diesel saved - cost of coffee husk

= 39 x 5 - 143.8 x 0.4

= 137.5 Rs. per hr.

Total operating hours of diesel genset assuming 8 hours per day and 150 working days per year

= 8 x 150

= 1200 hrs/yr

Annual saving = 1200 x 137.5

= Rs. 1,65,000

= Rs. 1.65 lacs

Total approximate capital investment on gasifier system with gas production rate of 350 Nm^3/hr is

Cost of gasifier = Rs. 40,000
Cost of related systems = Rs. 1,20,000
Total system cost = Rs. 1,60,000
= Rs. 1.6 lacs

Therefore simple pay back period will be

$$= \frac{1.60 \times 10^5}{1.65 \times 10^5} = 0.97 \text{ year}$$

= 1 year (approximately)

For this purpose total amount of coffee husk required annually will be

= 143.8 kg/hr x 1200 hrs p.a.

= 172.56 tons/year

Total amount of coffee processed at coffee curing works is 8000 tons (4800 tons of parchment coffee and 3200 tons of cherry coffee). Cherry coffee processing yields 50% coffee husk. Thus amount of coffee husk available annually is:

= 1600 tons

Thus there remains bulk quantity of husk which can be used for excess electricity generation or any other purpose. The above calculations assume that cherry husk can be directly used in downdraft gasifiers, which will have to be tested by experiments.

(iii) Using Gasifier for Coffee Roasting

In order to obtain coffee in the final usable form the dried coffee beans undergo roasting operation. Generally kerosene or high speed diesel (HSD) is used as fuel for coffee roasting which is usually a backyard operation of many coffee works carried out at cottage industry level. Approximately 25 kg/week, 1 ton/day and 30 ton/day coffee is roasted in small, medium and large coffee roasting factories respectively. In order to roast 75 kg of green coffee beans approximately 4 litres of HSD is consumed. Temperature in the roaster is maintained at around 400°C. Kerosene or HSD burners can be replaced with producer gas burners of an appropriate design, resulting in savings of Kerosene and/or HSD.

Sample calculation for a medium scale roasting unit is given here to compare cost of roasting per kg of green coffee.

$$\text{Amount of HSD required} = \frac{4}{75}$$

= 0.053 lit kg of green coffee

Fuel cost of roasting operation using HSD

= Rs. 0.265 per kg.

Calorific value of HSD = 10500 kcal/kg

Calorific value of producer gas = 1100 kcal/Nm^3

Specific gravity of HSD = 0.85

Amount of producer gas required, assuming same burner efficiency in both cases, will be

$$= \frac{0.85 \times 0.053 \times 10500}{1100}$$

$$= 0.43\ Nm^3/kg \text{ of green coffee}$$

Amount of coffee husk consumed to roast one kg of green coffee with gas yield of 2.2 Nm^3/kg

$$= \frac{0.43}{2.2}$$

$$= 0.2\ kg/kg$$

Cost of coffee husk = Rs. 0.40 per kg

Fuel cost of roasting operation using gasifier

$$= 0.2 \times 0.4$$

= Rs. 0.08 per kg

The actual cost will be slightly higher because of inclusion of electricity cost for blower operation and interest costs for gasifier set up, which have to be worked out on a plant-to-plant basis. It is, however, apparent that the cost of roasting can be substantially low if a gasifier system is employed for the purpose.

(iv) Utilisation of Waste Generated in the Instant Coffee Factories

A substantial quantity of residue (~ 80% of coffee processed) is generated during the process of instant coffee making. A visit to the factory of Brook Bond at Bangalore showed large amounts of coffee waste being dried at factory premises. The dried waste is currently being transported to another factory for utilisation in a specially designed boiler. The oil-fired boiler had been retrofitted by Thermax to change the fuel from LDO to coffee waste whenever desired. Hence the company was not interested in any alternatives, e.g. utilising coffee waste for gasification, at present. However, other factories in other locations may perhaps be interested in exploring gasification alternatives, but no further attempt have been made by the present team in visiting other instant coffee manufacturers.

5. TEA

India is the largest producer of tea in the world, accounting for about 28% of world production. Table 5.1 summarizes the statistics of tea production in India since 1977 [10].

Table 5.1 Some statistics of tea production in India

	1977	1978	1985	1986	1987	1988	1989	1990
North India								
Production, mkg	-	433.4	-	481.3	518.4	529.3	532.3	544.2
Area, ha	294,598	-	326,260	336,987	339,616	-	-	-
Av. yield rate, kg/ha	1,452	-	1,576	1,428	1,526	-	-	-
South India								
Production	-	130.4	-	139.5	146.9	171.8	151.8	170.5
Area	74,586	-	73,676	74,662	74,616	-	-	-
Av. yield	1,723	-	1,926	1,871	1,968	-	-	-
All India								
Production	-	563.8	-	620.8	665.3	701.1	684.1	714.7
Area	369,184	-	399,936	411,549	414,232	-	-	-
Av yield rate	1,507	-	1,641	1,508	1,606	-	-	-
Exports (tons)	229,640	176,051	-	203,149	201,891	221,540	223,000	-
Value (Rs. crore)	541.6	-	-	-	639.2	-	-	-

Tea Processing

In the processing of tea, energy is used at various unit operations. Two processing methods, "CTC" (crush or cut-tear-curl) and "Orthodox" (or classical), have generally been adopted by tea manufacturers. Around 56% of manufacturers use CTC and the remainder use orthodox method. The important processes and the respective process conditions involved in tea processing are shown in Fig. 5.1 [11].

The production of tea from green leaves is essentially a gradual oxidation process. Green leaves after harvest go through the following stages:

(i) withering
(ii) rolling and cutting
(iii) fermentation
(iv) drying
(v) grading

The first stage in tea processing is withering. Freshly plucked tea leaves which contain 75-80% moisture (w.b.) are spread at a rate of 10-20 kg/m^2 on a withering trough and allowed to wither artificially by means of warm air at 35°C for 16-20 hours. The desirable moisture content of withered leaf is 45-50% for orthodox type and 70% for CTC type of manufacture.

The next stage is rolling in the case of orthodox manufacture which twists the leaf and breaks it up. The tender portions of leaf after each rolling are separated from the bulk by mechanically sifting the contents. The moisture content of tea leaves after rolling (called 'dhool') is about the same as that before rolling. In case of CTC processing

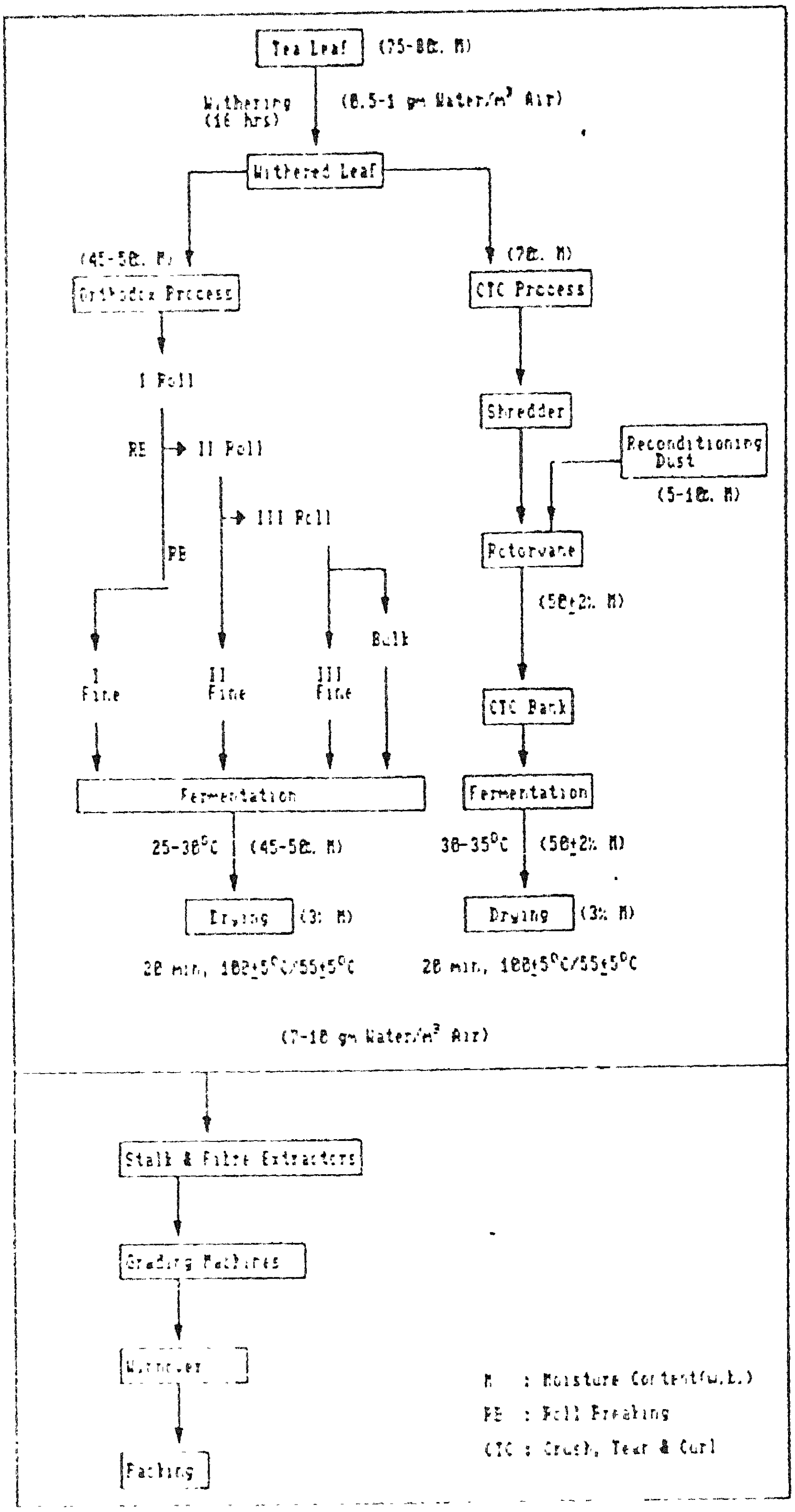

Fig. 5.1 Tea manufacturing process

the withered leaf is first passed through a shedder which disintegrates the leaf into uniform pieces and then through a rotorvane where mixing of ground black tea as reconditioning dust at 5-10% moisture level is carried out to regulate the moisture content of dhool at 50±2%. The leaves are finally cut into fine particles in CTC machines, four to five of them in series as shown in Fig. 5.2.

The third stage of processing is fermentation wherein the dhool after roll-breaking, spread in thin layers, is allowed to undergo oxidation for 1-2 hours in the presence of moist air at 25-30°C and 95% relative humidity. The CTC dhools are continuously rolled inside the fermenting drums for an hour with cold air entering the drum counter-currently.

In the final stage the fermented dhool is fed into continuous tray dryers or fluidised bed dryers where the moisture content is reduced to 3% (w.b.) by a stream of hot air at 100±5°C. The drying time is typically 24-26 minutes. The dried product is then graded and sent for packaging.

Energy Use Scenario in the Tea Industry

The thermal and electrical energy consumption figures for tea processing are shown in Table 5.2 [12]. It is apparent from Table 5.2 that drying consumes the highest fraction of energy. As mentioned earlier, coal is the main source of energy in the north eastern estates and firewood is predominantly used in southern states. With increased

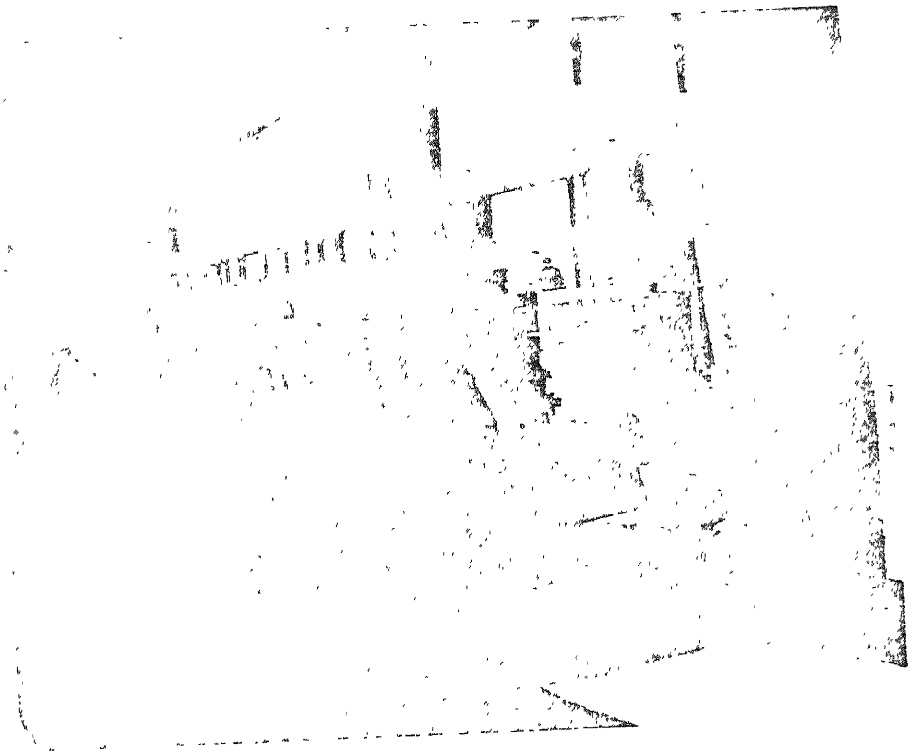

Fig. 5.2 CTC machines used in tea factories

Table 5.2: Average thermal and electric energy consumption in tea processing

Process Stage	Energy Consumption			
	CTC		Orthodox	
	Thermal (kWh/kg)	Electric (kWh/kg)	Thermal (kWh/kg)	Electric (kWh/kg)
Withering	0.70	0.11	1.08	0.14
Drying	3.80	0.04	3.30	0.04
Others (1)	--	0.45	--	0.40
Total	4.50 (2)	0.60 (3)	4.38	0.58

(1) Rolling, fermentation, grading and packing
(2) Range evaluated : 3.78 - 5.22
(3) Range evaluated : 0.55 - 0.65

availability of oil and natural gas, the northern estates are utilizing more and more of oil and gas, but the southern estates are still using firewood grown on captive forests. Consumption of various fuels in the southern tea estates is shown in Table 5.3 [11], which clearly indicates the over dependency on firewood. Consumption of coal is decreasing steadily, as can be seen in Table 5.3, owing mainly to major shortage for transport of coal to the consuming centre which makes coal supply unreliable. The trend in fuel cost per kg of made tea is shown in Table 5.4 [11].

The figures given in Table 5.4 are ten year old, but nevertheless show that firewood by far is the cheapest fuel available to the planters. The figures also reveal that the

Table 5.3 : Consumption of various energy sources in the South Indian tea industry

Energy Source	1978	1979	1980	1981
Firewood (tonnes)	144548 (46%)	210627 (57%)	171010 (51%)	184178 (58%)
Coal (tonnes)	44990 (34%)	36162 (24%)	30737 (22%)	26490 (20%)
Leco (tonnes)	---	---	---	2648 (3%)
Furnace oil	14447 (20%)	15868 (19%)	20576 (27%)	13727 (19%)

Table 5.4 : Trends in fuel cost per kg of made tea in South India (Rs. per kg)

Fuel	1978	1979	1980	1981
Firewood	0.14	0.15	0.19	0.22
Coal	0.27	0.32	0.44	0.58
Furnace oil	0.49	0.56	0.80	1.03
Leco	---	---	---	0.56

share of energy cost of made tea is very small, which is perhaps the reason for complacency among the planters in energy related matters.

A more serious problem faced by the tea factories is the power cut, which is a regular phenomenon in hill areas of the Nilgiris where majority of the tea factories are located in South India. Hence the use of diesel gensets is a common feature in the tea industry.

As a major fraction of energy consumed is spent in the drying process an attempt is made to analyze the process in greater detail. The drying system consists of an air-heater, a feeding system for tea, a drying chamber, a blower and associated ducting and a cyclone separator for recovering tea dust in the hot flues. In older tea factories, a system of continuous tray drier is used, but these are being replaced by fluidised bed drying system in modern large scale tea factories.

The air heater is essentially a furnace embedded with a large number of air ducts with an elliptical cross section. Heat generated by burning logs of firewood is transferred to the air by radiation and convection. The arrangement of air pipes is in such a manner as to allow multiple passes of air. Photograph in Fig. 5.3 shows conventional furnace and air heater. Schematic diagram showing conventional air heater and continuous tray dryer is shown in Fig. 5.4 [13]. Feeding of logs into the furnace is manual. The temperature of the hot air is closely monitored by visual observation through a dial type thermometer and feeding of logs is regulated so as to maintain the air temperature at a predetermined level.

The thermal efficiency of the air heater can be calculated by noting the air flow rate, temperature and fuel consumption. Calculations for coal-fired air heater and for a wood-fired air heater, based on actual plant data, are shown in Table 5.5.

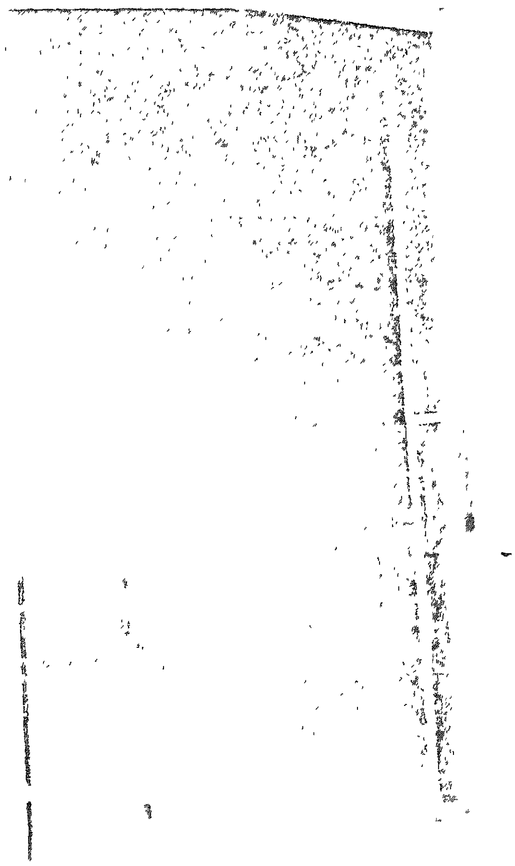

Fig. 5.3 Furnace and tube bank for air heating in tea factory

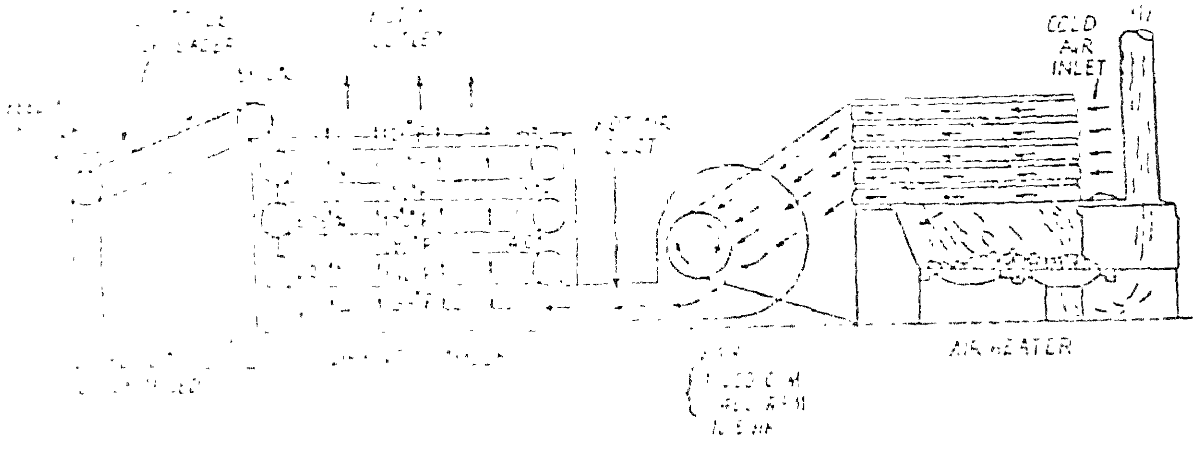

Fig. 5.4 Air heater and continuous tray dryer used in tea factory

Table 5.5 : Thermal efficiency calculations for air heaters

	Coal fired air heaters	Wood-fired air heaters
Hot air temperature	90°C	140°C
Mass flow rate of air	23,338 kg/hr	13,000 kg/hr
Ambient temperature	20°C	20°C
Heat gain of air	3,92,079 kcal/hr	3,79,080 kcal/hr
Tea production rate	190 kg/hr	350 kg/hr
Specific fuel consumption	1.4 kg/hr	0.9 kg/hr
Fuel consumption	266 kg/hr	315 kg/hr
Calorific value of fuel	6,000 kcal/kg	4,000 kcal/kg
Heat input rate	15,96,000 kcal/hr	12,60,000 kcal/hr
Thermal efficiency	24.5%	30.0%

It can be seen from Table 5.5 that though the performance of the drier system has considerably improved due to technological innovations there has not been a significant improvement in the efficiency of the air heater. This is perhaps due to inherent limitations in the design of the air heater. As the air heater is necessarily bulky due to provision of a large number of air pipes, heat losses from the air heater surface would be substantial. Another major loss would be through the flue gases which leave the chimney at about 130-140°C.

From the above discussion it is apparent that a combined heat and power (CHP) system would be highly desirable for the tea industry in general. It is also highly desirable to evolve system which can use firewood in a more efficient way as continued use of this natural resource in a less efficient manner would lead to supply constraints and would encourage use of petroleum based fuels in future.

Some Technology Options for Combined Heat and Power Systems

Industrial use of combined heat and power (CHP) systems or cogeneration systems leads to small, dispersed electric power generation installations - an alternative to complete reliance on grid power supply. Fuel saving is the major incentive for the use of CHP systems. Since all the heat engine based electric power systems reject heat to the environment, this rejected heat can be used to meet all or part of on-site local thermal energy needs. Use of rejected heat usually has no effect on the amount of primary fuel used, yet it leads to a saving of the fuel that could otherwise be used for the thermal energy process. Heat engines also require a high temperature thermal input and in some situations can obtain the input thermal energy as the rejected heat from a higher temperature thermal energy process. In the former case, the cogeneration process employs a heat engine topping cycle; in the latter case, a bottoming cycle is used. CHP systems can be designed from two perspectives: they can be sized to meet process heat sized to meet the process needs and electrical product produced is treated as a by-product, or they can be sized to meet electrical power demand and the rejected heat is then used to supply process heat needs. The latter approach is the likely one, if utility ownership is involved.

Most common heat engine systems for CHP systems are:

- Steam turbines (back pressure and extraction type configurations)
- Combustion gas turbines (open or closed cycle type)
- Diesel engines

Each heat engine type has unique characteristics making it better suited for CHP applications than others. For example, engine types can be characterised by:

- Power to heat ratio at design point
- Efficiency at design point
- Capacity range
- Power to heat ratio variability
- Part load (off-design) efficiency
- Multi-fuel capability.

The major heat engine types are described in terms of these characteristics in Table 5.6 [14].

Representative CHP systems for each heat engine types are described in the following sections.

Steam Turbine Systems

Both back pressure and extraction condensing steam turbine systems can be used. Typical configurations are illustrated in Figs. 5.5 and 5.6. The back pressure configuration is better suited for applications in which

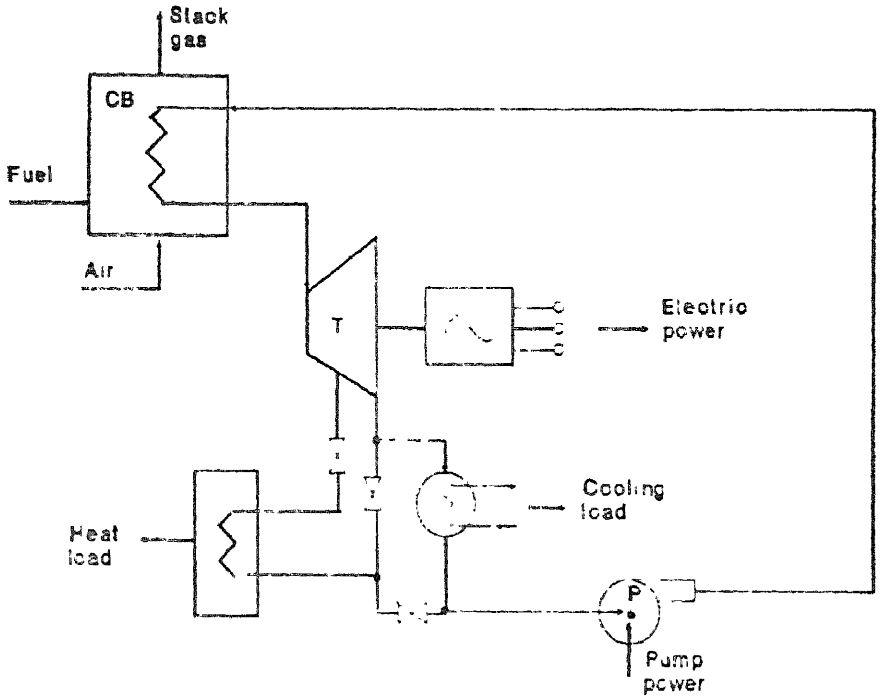

Fig. 5.5 Extraction-condensing steam turbine cogeneration cycle
CB = cobustor, P = pump, T = turbine

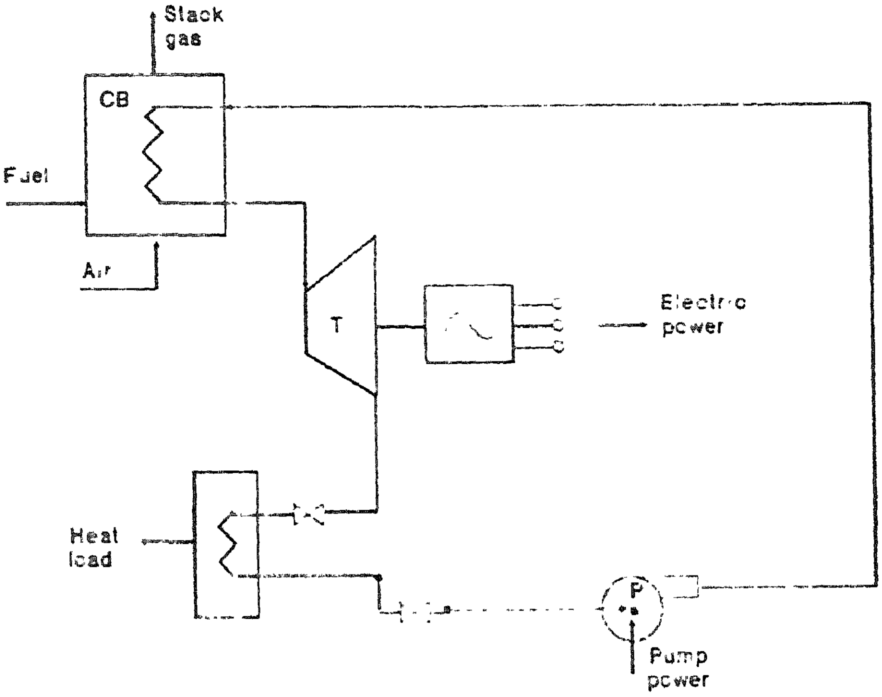

Fig. 5.6 Back pressure steam turbine cogeneration cycle
CB = cobustor, P = pump, T = turbine

Table 5.6: Cogeneration characteristics for heat engines

Engine type	Efficiency at design point	Part load efficiency	Multifuel capability	Maximum temperature of recoverable heat (^{o}C)	Recoverable heat kcal/kWh	Typica to hea
Steam turbine						
Extraction condensing type	0.25-0.30	Fair	Excellent	93-315	2800-8800	0.10-
Back pressure type	0.20-0.25	Fair	Excellent	93-315	4300-17600	0.05-
Combustion gas turbine	0.25-0.30	Poor	Poor	538-649	800-2800	0.30-
Diesel engine	0.35-0.40	Good	Fair to poor	260-371	100-1600	0.60-

power to heat ratio is low and relatively fixed. Extraction condensing steam turbines offer greater variability of power to heat ratio (through changes in the amount of extracted steam) and a higher power to heat ratio (when extracted steam is minimised). The extraction condensing cycle must always condense the steam flow which passes through the full pressure ratio of the turbine; the extracted steam may or may not need to pass through the condenser, depending on the temperature limits of the heat load and whether or not it condenses the steam flow. For the back pressure configuration, the need for a condenser depends on whether the heat load itself condenses the steam flow or not.

Combustion Gas Turbine Systems

Gas turbine operates on the Brayton thermodynamics cycle. In a combustion turbine a clean fuel is burned directly in the compressed air working fluid and the combustion products are then expanded through the turbine and exhausted to the atmosphere. The combustion gas turbine system shown in Fig. 5.7 provides a higher power to heat ratio than typical steam turbine configuration (See Table 5.6). Of all the systems considered the combustion gas turbines also provides heat at the higher temperature (upto 650°C. Major draw back of combustion gas turbine system is their poor part load efficiency and the requirement for clean fuel to avoid erosive or corrosive damage to turbine.

Diesel Engines

Diesel engines have been used in small scale cogeneration applications. They are characterised by high engine efficiency (See Table 5.6), good pard load characteristics, a relatively low rejected heat temperature and a high power to heat ratio. Diesel engines supply process heat in two forms: Low temperature (93 to 121°C) engine coolant, and higher temperature (260 to 370°C) exhaust gas. The diesel engine as a CHP system is illustrated in Fig. 5.8.

CHP System for Tea Industry

Here simple calculation is given to calculate power to heat ratio for the typical tea factory in order to decide which CHP system is suitable.

Made tea output per dryer = 300 kg/hr

Amount of hot air needed for tea drying at 120°C for Pandian plug flow tea dryer (the value is taken from their product catalog).

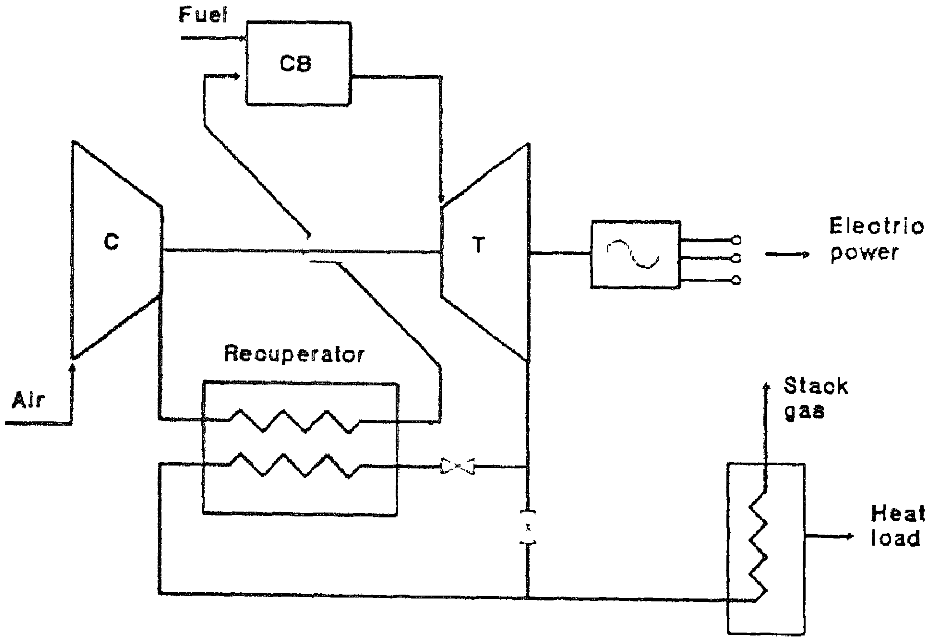

Fig. 5.7 Combustion gas turbine cogeneration cycle
C = compressor, T = turbine, CB = combustor

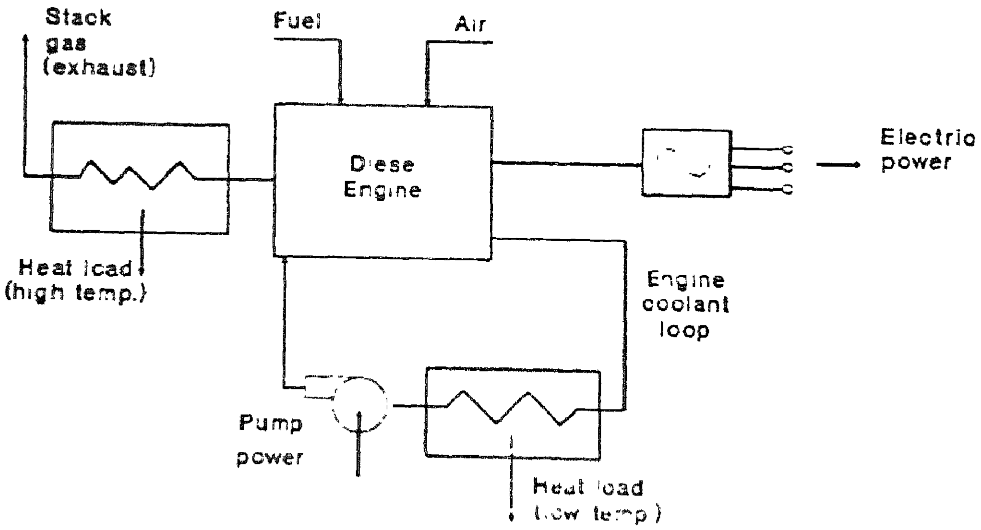

Fig. 5.8 Diesel engine cogeneration cycle

= 9.5×10^3 Nm^3/hr

= 11.4×10^3 kg/hr

Amount of heat required to heat air from 20°C to 120°C

= 273600 kcal/hr

= 318 kW (thermal)

Amount of electricity consumed (from Table 5.2)

= 0.6 kWh/kg

Electrical power required for dryer capacity of 300 kg/hr will be

= 180 kW

Power to heat ratio = 0.566

Therefore from Table 5.6, it can be observed that diesel engine system is th suitable cogeneration option for tea industry.

Scope for Using Wood Gasifier Systems in Tea Industry

As discussed above, diesel engines can be used to meet the process heat and electric power demand of tea manufacturing factories. Majority of the tea estates at present depend on firewood which is grown on captive forests. Operating diesel engines on dual fuel mode by employing gasifier systems can result in a large saving of diesel, prices of which are rising sharply and steadily due to its acute shortage in the hilly regions of South India. A sample calculation to determine savings that can be achieved by use of gasifier system is given below:

Installed capacity of generator = 180 kW

Diesel consumption = 54 lit/hr
(@ 0.3 lit/kWh)

Producer gas (with calorific value = 1100 kcal/Nm^3) required to replace 65% of diesel in dual fuel mode operation assuming equal thermal efficiency for both fuels will be

= 438 Nm^3/hr

Specific gas production = 2.3 Nm^3/kg

Wood consumption rate = 190 kg/hr

Price of diesel = Rs. 5/lit

Price of wood = Rs. 0.50/kg

Therefore for an 8 hour operation per day and for 300 operating days per year the net annual saving will be:

$$= \{(54 \times 5) - (54 \times 0.35 \times 5) - (190 \times 0.5)\} \times 2400$$

= Rs. 1,93,000 p.a.

In addition to this, fuel required for process heat can be saved if heat rejected from diesel engine is utilised.

Specific wood consumption for drying = 0.9 kg/kg of made tea

Wood consumption for 300 kg/hr dryer capacity = 270 kg/hr

Annual wood consumption = 6,48,000 kg

= Rs. 3,24,000

Total saving if gasifier system is used for operating diesel engine on dual fuel mode and heat rejected from it is utilised for process heat (diesel engine cogeneration system) will be

= Rs. 5,17,000 p.a.

Initial capital investment required for this purpose excluding diesel generator set will be approximately:

Gasifier system (500 Nm^3/hr) = Rs. 2,00,000
Gasifier related systems = Rs. 5,00,000
Heat exchangers for air heating = Rs. 2,50,000
Total = Rs. 9,50,000

The simple pay back period works out to be approximately 2 years.

Using Producer Gas for Tea Drying

Producer gas obtained from the gasifier after thorough cleaning can be burned with excess amount of air in the burner to bring the temperature of air-flue gas mixture to 120°C and this in turn can be directly pass through tea dryer. Complete cleaning of gas is the main area which needs developmental efforts. Since in this system heat exchanger component of the present tea drying system is eliminated it may obviously result in better thermal efficiency or in other words saving of fuel wood. Following calculation give approximate idea of specific fuel consumption values.

Dryer capacity = 300 kg of made tea/hr
Hot air flow (120°C) = 11,400 kg/hr

Amount of gas required to heat air from 20°C to 120°C assuming 90% burner efficiency will be:

= 275 Nm^3/hr

Specific gas production = 2.3 Nm^3/kg

Wood consumption rate = 120 kg/hr

Amount of wood required to produce one kg of made tea = 0.4 kg/kg

Thus the fuel wood consumption rate can be brought down to less than half (from the present level of 0.9 kg/kg) by the use of gasifier systems.

6. TOBACCO

Even though serious health hazards are associated with the consumption of tobacco, it remains one of the world's largest cash crop grown in around one hundred countries. India produces about 450 million kg of tobacco annually from an area of about four lakh hectares which accounts for about nine per cent of the world area and 7.5 per cent of world production. It has 0.3 per cent of the total cropped area in the country (See Fig. 6.1). Endowed with various agro-climatic zones, India grows all types of tobacco (except oriental), which are broadly classified as flue-cured virginia (FCV) (cigarette tobacco) and non-virginia types. FCV tobacco accounts for 30 per cent of the area and 22 per cent of production while the non-virginia type comprising bidi, natu, chewing, hookah, cigar and cheroot, burley and snuff tobaccos, accounts for the remaining 70 per cent of the area with a production of about 350 million kg. Tobacco provides about Rs. 1,500 crores of Central excise revenue and earns Rs. 150 to 170 crores of foreign exchange through exports. Table 6.1 gives details about area and production of various tobacco varieties in India [15]. FCV tobacco, the major exportable type, is mainly grown in Andhra Pradesh (10,000 ha) and Karnataka (20,000 ha).

Tobacco Flue Curing Process

A brief summary of the flue-curing process is perhaps helpful in order to appreciate its energy related implications. The description here is based on the

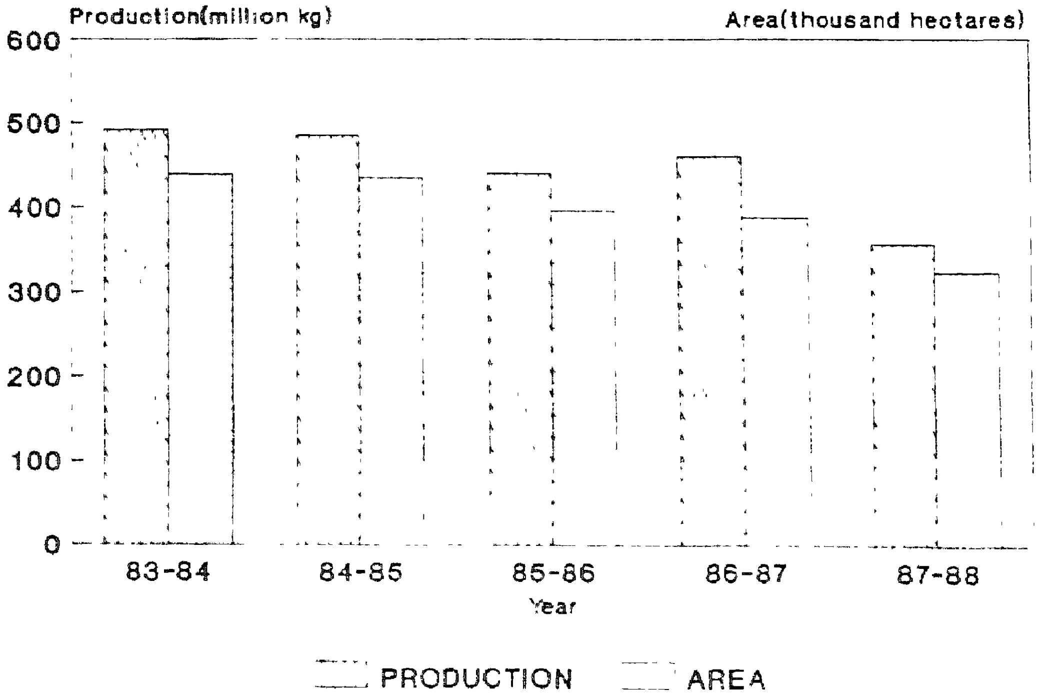

Fig. 6.1 Production and Area of different Tobacco varieties

Table 6.1 Area and production of tobacco varieties

Type	1983-84		1984-85		1985-86		1986-87		1987-88	
	Area+	Produ-ction*	Area	Produ-ction	Area	Produ-ction	Area	Produ-ction	Area	Produ-ction
Virginia	152.3	130.0	133.1	110.0	115.9	79.6	117.9	109.5	88.0	64.3
Natu	40.0	53.0	48.0	53.0	42.0	58.0	37.0	45.0	35.0	40.0
Bidi	128.0	175.5	126.0	175.0	127.0	173.0	130.0	185.0	100.0	135.0
Cigar & Chercot	14.0	14.9	16.6	19.4	12.4	17.7	10.0	11.0	10.0	10.0
Hookah	29.7	31.2	30.0	33.0	28.0	30.0	24.0	28.0	24.0	28.0
Chewing	69.2	78.7	75.5	89.0	67.0	75.0	65.0	78.0	60.0	75.0
Snuff	6.5	9.2	7.4	6.5	4.7	7.9	5.3	5.3	6.9	6.6
Total	439.7	492.5	436.6	485.9	397.0	441.2	389.2	461.8	323.9	358.9

+ Area : 1,000 hectares
* Production : million kg

conventional practices followed in Andhra Pradesh but should be valid for other developing countries also with minor local variations [16].

Tobacco leaf looses much of its value if it is not harvested as soon as it ripens. Moreover, the plucked leaf must be cured without undue delay, otherwise heating up and spoilage occurs, especially if it is stored in bulk or heap. As a consequence, a decentralised curing facility must be available in the vicinity of the tobacco crop to take leaf whenever it is ready. In Andhra Pradesh alone, there are about 50,000 barns owned by the individual farmers. On an average, eight batches are cured in a barn in one season. Each batch consists of about 1.5 tonnes green leaves and yields around 250 kg cured leaves.

The flue curing process brings down the water content from 80-85% (w.b.) in green leaf to 6-8% (w.b.) in cured leaf. The curing takes place through four distinct stages.

(i) Yellowing

(ii) Colour fixing

(iii) Leaf or laminar drying

(iv) Stem or midrib drying.

During the yellowing stage certain biochemical changes are brought about through decomposition and oxidation of proteins and fats under high humidity conditions in order to improve smoking quality. The green chlorophyll is also broken at this stage thereby exposing yellow pigments like xanthophyll and carotin. Therefore, during first 24-40 hrs when the leaves are turning yellow, the temperature is kept low (37-38°C) and the humidity is maintained high. The ventilators are kept closed to conserve moisture. As yellowing progresses, the temperature is gradually raised at the rate of 0.5-1°C per hour to about 40-41°C by the time most of the leaves are yellowed. As long as the leaves have sufficient moisture they continue to change colour gradually from green to yellow and then to light brown and finally to dark brown. It is therefore necessary to fix the colour of the leaves by reducing the moisture content when a majority of the leaves in the barn have attained the desirable golden yellow colour. The temperature is raised by 1.5-2°C an hour to about 51-52°C and the ventilators are opened. During colour fixing stage, further biochemical changes are arrested by thermal desiccation. After the colour of the leaves is fixed, temperature is raised rapidly to about 65-66^{o}C which is maintained until the laminae of the leaves are dry. In order to dry the midribs completely, the temperature is further raised to about 70^{o}C and maintained till the end of drying. For the midrib drying stage the ventilators are kept closed to conserve heat.

Figure 6.2 shows the time-temperature-humidity profile for these stages, along with the positions of the bottom and top ventilators, as a guideline for a good curing schedule. The essential feature of the tobacco-curing process is that the reaction rates are initially accelerated by raising the temperature under a high humidity environment and then abruptly terminated at the right point by rapid desiccation of the leaf. The crucial requirement is that the barn temperature must exhibit a steady rising trend accompanied by an uninterrupted removal of moisture in order to avoid damaging the leaf.

Tobacco Curing Barns

The barn, made of stones, or more often of bricks, are more or less of standard design. The floor size is 4.9 m x 4.9 m and side walls are 5.5 m high. The roof, constructed of corrugated galvanised iron sheets, is of gable (hip) design, which at the center rises 7 m from the floor. A number of openings and windows, with suitable flaps, are provided at the bottom and in the roof for ventilation. Tobacco leaves are loaded in the barn of 7 bamboo tiers which

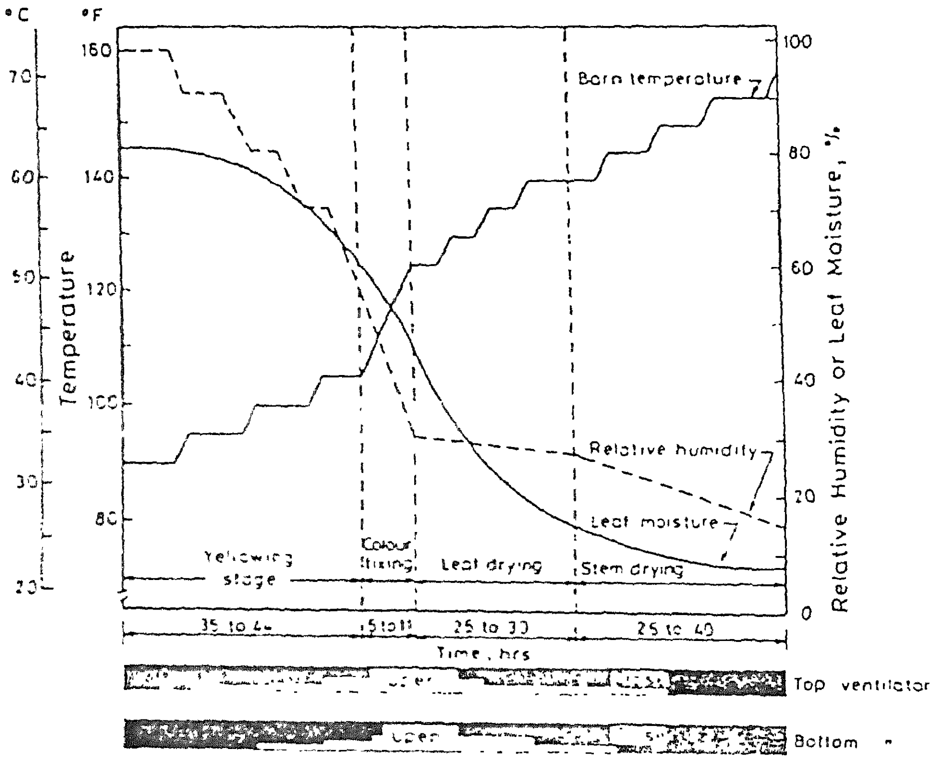

Fig. 6.2 Typical flue curing schedule for tobacco

are arranged 0.61 m apart vertically; the first tier is 2 m above the floor level.

The flue pipe system, located at the base of the barn, provides indirect heating of the leaf. It comprises a fire-box and a combustion chamber which extends through the barn wall into a 1.75 m long cast iron pipe, followed by a 0.29 m diameter mild steel flue pipe, as shown in Fig. 6.3. In some instances the cast iron pipe, which can become red hot in the course of operation, is jacketed for preheating of ambient air; the hot air is piped directly into the barn as a supplementary heat source and for equalization of temperature at the floor level. The flue pipe runs straight down the middle of the barn floor and ends in a T-junction near the rear wall. Each branch then follows around the wall at a distance of 15 to 30 cm, to form two rectangular shaped loops, all the while rising 1 cm per meter running length of the pipe. The two ends of the loops meet at a height of about 0.3 m above the inlet, join and pass through the wall over the fire-box into a 3 to 3.5 m tall chimney.

Energy Scenario in Tobacco Curing Barns

Virginia tobacco, which is the most widely grown tobacco variety, is flue-cured through an energy intensive process. Heat required in kcal for a barn with 1452 cubic feet capacity of conventional construction capable of curing 620 kg of green tobacco leaves at Rajahmundry is given in Table 6.2 [17].

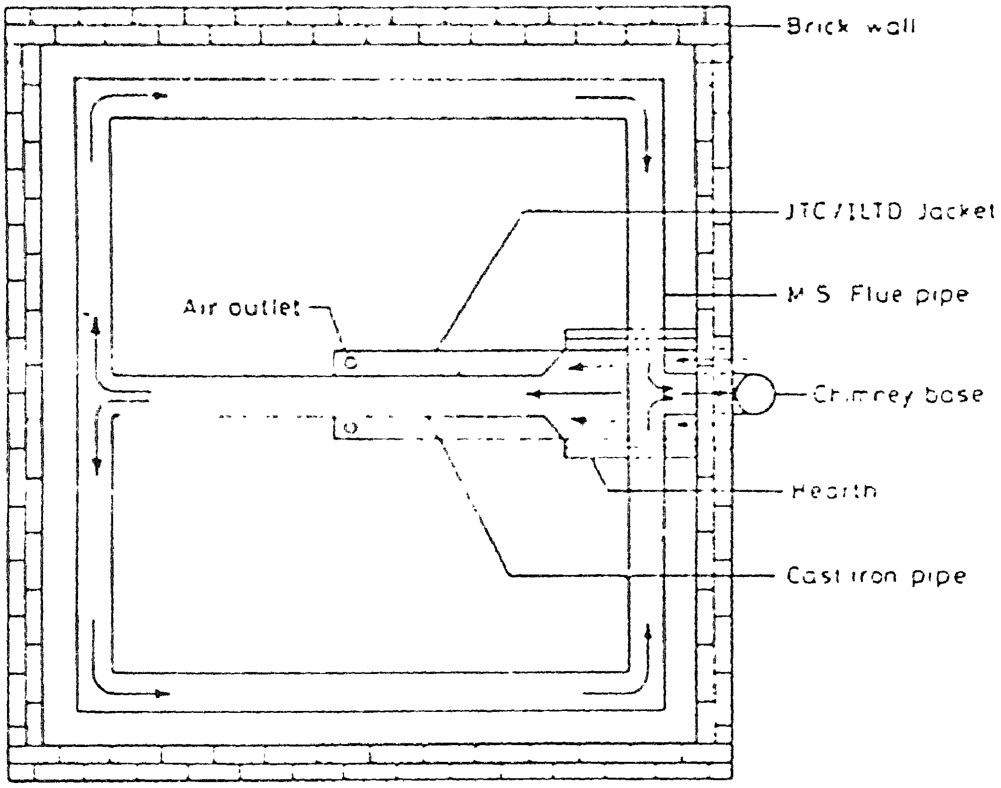

Fig. 6.3 Flue pipe system in a standard tobacco curing barn

Table 6.2 Heat required in different stages of tobacco drying

	Process (curing)	Barn Losses	Required by Fixtures	Total
Yellowing	675	18,880	774	80,670
Colour fixing	3,758	24,859	3,870	32,487
Laminar drying	227,913	117,852	4,839	350,333
Mid-rib drying	75,908	211,425	3,870	291,203
Total	308,254	372,746	13,352	694,352

Note: All values are in kcal

In most developing countries, wood is widely used as the fuel for curing tobacco. As much as 130 m^3 wood is burnt for every tonne of cured tobacco [18]. Worldwide about 2,50,000 hectares of trees are used up annually for tobacco curing, which comes to the astonishing figure of 12% of total tree fellings. In principle, the firewood requirement can be met by growing trees on dedicated energy farms. In reality, however, most land holdings in the developing countries are simply too small to permit diversion from staple food or cash crops. Besides, four to five hectares must be set aside for tree coverage in order to meet the energy demand arising from one hectare under the tobacco crop on an ongoing basis.

In Andhra Pradesh, depending upon availability and cost, the farmer uses either firewood or coal, or even both. In the year 1986-87, in Andhra Pradesh, the price of government subsidized coal with 40% ash content was about Rs.

0.35 per kg, or green wood with 20% moisture around Rs. 0.45 per kg [19]. Due to rapid depletion of forest, majority of tobacco curing barns are now using coal as fuel.

It also turns out that because of defective barn construction and erratic and empirical operating practices, vast quantities of fuel are wasted in the curing process. Upto 300% variations in fuel consumption figures have been noted in Andhra Pradesh, where normally a farmer consumes 8-10 tonnes per tonne of cured leaves [19]. These data suggest that considerable scope exists for improving the thermal efficiency of the barns, provided relatively simple and inexpensive measures can be introduced in the field.

Scope for Improving Thermal Efficiency of Barns

Often the design of the barn and flue pipe layout are such as to give high and fluctuating temperatures and humidity. These in combination with high air exchange rates, often result in poor quality curing, low grade tobacco, and high fuel consumption. Fuel consumption depends on furnace and barn design, flue pipe layout, and fuel quality. Methods of operation, especially control of air flows, determine curing time and hence fuel consumption. For a curing time of 90 hours consumption is about 8.7 kg/kg of dry leaves or 1.0 kg/kg of wet leaves. In conventional barn where coal is used as fuel 4 kg of coal is consumed in order to obtain 1 kg cured leaf [7].

In a typical curing operation of 100 hours, heat losses due to roof ventilation, conduction (through barn structure), chimney stack, and furnace convection/radiation are in the range of about 16-20, 14-18, 13-15 and 13-17%, respectively. During the study conducted on tobacco curing in northern Thailand since 1984 it was found that insulation of the barn structure and a simple improvement on furnace control can reduce the fuel wood consumption from 7 kg/kg cured leaf to respectively 6.2 and 5.4 kg. Thus a net fuel wood saving of 22% can be achieved by combining both the improvements with estimated pay back period of only 1.3 curing season [7]. Of these, modifications to the furnace appears to offer greater returns.

However, the most effective way to reduce consumption is to reduce the 38% heat losses through the flue to the outside atmosphere. The best way is probably to use a gasifier. If LPG is used as fuel, direct heating can be done with the hot gas from the burner passing through the tobacco itself [7]. This is not possible in the case of wood or coal as a fuel. But it may become possible if the wood or available suitable biomass is gasified first and then the combustible producer gas obtained from gasifier, after proper cleaning, can be burned and the resulting air-flue gas mixture can be passed through the barn for direct heating. Rough calculations indicate that the fuel consumption figure with gasifier based system may be around 5 kg of wood per kg of cured leaf compared to the present value of 7 kg/kg.

Though there seems to be little scope for utilising wood gasifier coupled tobacco barns in India, such systems, once developed, can probably be exported to other countries using firewood.

Scope for using Tobacco Dust in Gasifier for Fuel Oil Savings

Cigarette making industries require large quantity of flue cured virginia tobacco leaves and significant quantity of tobacco waste is produced in the form of dust. For example, I.T.C. Ltd., one of the largest manufacturers of cigarettes requires 60-70 tonnes of tobacco leaves per day at their factory in Bangalore. Approximately 10% of it is produced as tobacco waste in dust form amounting to 6-7 tonnes per day. About 300 kg of tobacco waste made available by ITC Ltd. are briquetted successfully at the briquetting factory at Tumkur near Bangalore and tried for gasification in the down-draft throatless gasifier developed by TERI in an earlier project during the course of this study. Diesel replacement of 60-80% is achieved during initial trial runs.

The Bangalore factory of ITC requires about 25,000-30000 liters of fuel oil per day for processing of 60,000-70,000 kg of tobacco leaves per day. Furnace oil and light diesel oil (LDO) are used for firing the boilers. The following calculations indicate the viability of utilizing tobacco waste for saving fuel oil in substantial quantities.

Tobacco waste produced	6 ton/day
Specific gas production rate	2.3 Nm^3/kg

Gasifier rating (for a 16 hr/day operation)	860 Nm^3/hr or 9,46,000 kcal/hr or 1100 kW (thermal)
Quantity of fuel oil saved (assuming identical efficiencies for firing with gas and fuel oil)	105 lit/hr
Annual fuel oil savings (assuming 16 hrs/day and 300 days/yr)	5,04,000 lit/yr
Annual savings (@ Rs. 5/lit)	Rs. 25.2 lakhs
Electricity consumption for briquetting (@ 0.1 kWh/kg briquetted material)	600 kWh/day
Annual electricity charges (@ Rs. 2.0 Rs./kWh)	Rs. 3.6 lakhs
Net savings	Rs. 21.6 lakhs
Approximate initial cost	Rs. 42 lakhs
Simple pay back period	2 years

The gasifier system being a renewable energy equipment, is eligible for 100% depreciation in the first year and hence the payback period would be even less. Also, the initial cost for subsequent systems installed in other factories would be considerably less and hence the pay back periods would be correspondingly lesser. Thus utilization of tobacco waste through the briquetting and gasification scheme can thus result in substantial fuel oil savings.

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ACKNOWLEDGEMENTS

Work described in this report was performed as a phase-I of the project "Design, Fabrication and Testing of a Complete Dryer System for Some Cash Crops using Biomass Gasifier", (Ref. No. 203/01/6/89-BM) funded by the Department of Non-conventional Energy Sources, Ministry of Energy, Government of India, New Delhi. The authors are grateful to Department of Non-conventional Energy Sources for supporting this project. Dr. V. Govindarajulu of UPASI Tea Research Sub-station, Vandiperiyar, Mr. Haridas and Mr. Ramakrishna of Tata Tea Ltd., Munnar, Mr. T.G. Rajendra and Mr. Mammen Phillip of Kerala State Cashew Development Corporation (KSCDC), Quilon, Dr. M.S. Chari of Central Tobacco Research Institute (CTRI), Rajahmundry, Mr. J. Sunil Prasad and Mr. V. Rama Rao of Mysore Coffee Curing Works, Chikamagalur, Mr. Ganesh and Mr. Shanmugan of ITC Ltd., Bangalore, Mr. C.K. Somasunder of Allansons Ltd., Mangalore, Mr. Shankara Murthy of Jayanthi Coffee Works, Chikamagalur, Dr. R. Naidu and Dr. K.J. Madhusoodhanan of Indian Cardamom Research Institute (ICRI), Myladumpara, Mr. Kartikeyan, Mr. Pannu Singh, Mr. Nand Kumar of M/s. Harissons Malayalam Ltd., and many others have given valuable information and support during the survey and authors are indeed grateful to them. The support and encouragement of Dr. R.K. Pachauri, Director, Tata Energy Research Institute is gratefully acknowledged. Thanks are due to Mr. P. Raman for useful discussion on various topics during the course of the study and Mr. Kamal Sharma for typing this manuscript and to all colleagues of TERI who have helped in several matters during the course of the work.

ANNEXURE I

LIST OF RESEARCH INSTITUTES AND ESTATES/CURING HOUSES VISITED DURING THE SURVEY IN SOUTH INDIA

LIST OF RESEARCH INSTITUTES AND ESTATES/CURING HOUSES VISITED DURING THE SURVEY IN SOUTH INDIA

Cardamom

1. University of Agricultural Sciences, Bangalore (Karnataka).
2. Regional Research Station, University of Agricultural Sciences, Mudigere (Karnataka).
3. School of Energy, Madurai Kamaraj University, Madurai (Tamil Nadu)
4. Cardamom Research Centre, Pambadumpara (Kerala).
5. Indian Cardamom Research Institute, Myladumpara (Kerala).
6. UPASI, Vandiperiyar (Kerala).
7. Vellimale Estate, Vandanmettu (Kerala).
8. Lakshmi Vilas Estate, Vandanmettu (Kerala).
9. Kylaspara Estate, Kylasnadu (Kerala).
10. Plakkad Estate, Vandiperiyar (Kerala).
11. Kudukarnam Estate, Peermedu (Kerala)
12. Pambnar Estate, RBT Group, Pambnar (Kerala).
13. Arnakal Estate, AVT Group, Vandiperiyar (Kerala).
14. Winderemere Estate, Pothamedu (Kerala).
15. Manalil Estate, Pallivasal (Kerala).
16. Masjish Gardens, Pothamedu (Kerala).

Cashew

17. Kerala State Cashew Development Corporation Ltd., Quilon (Kerala).
18. Lakshmi and Co. Cashew Factory No. 44, Quilon (Kerala).
19. Century and Co. Cashew Factory No. 51, Quilon (Kerala).
20. Cashew Processing Factory, Achal Industrial Estate, Mangalore (Karnataka)

Coffee

21. Central Coffee Research Institute, Balehonnur (Karnataka).
22. Mysore Coffee Curing Works Pvt. Ltd., Chikmagalur (Karnataka).
23. Chikmagalur Coffee Curing Works, Chikmagalur (Karnataka).
24. Jayanthi Coffee Works Ltd., Chikmagalur (Karnataka).
25. Lalithadri Estate, Hosepeth (Karnataka).
26. Kothari Industrial Corporation Ltd., Hassan (Karnataka).
27. Ganga Coffee Curing Works Pvt. Ltd., Hassan (Karnataka).
28. Hassan Coffee Curing Works, Hassan (Karnataka).

Tea

29. UPASI Tea Research Institute, Valparai (Tamil Nadu).
30. UPASI Coonnoor (Tamil Nadu)
31. Peria Karmalai Tea and Produce Co. Ltd., Coimbatore (Tamil Nadu).
32. INDCO Tea Factory, Ithelar, Ooty (Tamil Nadu).
33. INDCO Serve, Coonnoor (Tamil Nadu).
34. INDCO Tea Factory, Koribetta (Tamil Nadu)
35. INDCO Tea Factory, Kotagiri (Tamil Nadu)
36. The Pandian Engineering Industries, Kotagiri (Tamil Nadu).
37. Arnakal Tea Factory, AVT Group, Vandiperiyar (Kerala).
38. Pallivasal Tea Factory of Tata Tea Ltd., Pallivasal (Kerala).

Tobacco

39. Central Tobacco Research Institute, Rajahmundry (Andhra Pradesh)
40. Katheru Farm, Rajahmundry (Andhra Pradesh).

Others

41. Central Plantation Crops Research Institute, Kasaragod (Kerala).
42. Central Food Technological Research Institute, Mysore (Karnataka).
43. Rubber Board Development Division, Cochin (Kerala).

ANNEXURE II

PROPOSALS

I. Development of gasifier based cardamom drying system

II. Development of 100 kW power plant utilising cashewnut shell through biomass gasification route

III. Development of 200 kW power plant utilising coffee husk through biomass gasification route

IV. Design, fabrication and field testing of gasifier based coffee roasting system

V. Design, Fabrication and testing of a tea drying system using biomass gasifier

VI. Development of a briquetting-gasification system for utilisation of tobacco waste

PROPOSAL - I

1. Title of the Project : **Development of gasifier base cardamom drying system**

2. Name and Address of the Investigator : Dr. V.V.N. Kishore
Senior Fellow
Tata Energy Research Institute
232 Jor Bagh
New Delhi - 110 003.

3. Name of the Institute at which project will be carried out : Tata Energy Research Institute

4. Name(s) of the probable Institution(s) which may be involved in the project :
   1. United Planters Association of South India (Kerala State)

      and

   2. M/s. Harrisons Malayalam Limited, (Kerala State)

      or

   3. M/s. A.V. Thomas Group, Vandiperiyar, (Kerala)

      or

      Any other estate

5. Duration of the Project : 36 months

6. Total amount of assistance sought : Rs. 31.98 lacs

7. Detailed project proposal :

7.1 Preamble

Curing of crops like cardamom, tobacco etc. is an energy intensive operation. The present curing methods are not energy efficient, the main reason being lack of proper heat exchange equipment. A survey of conventional cardamom curing chamber indicates that present curing chamber are operating on very low efficiency of the order of 3-8%.

Conventional curing chambers operate on principle of space heating. Hot flue gases obtained from combustion of fuel wood are passed through flue pipe laid inside the curing chamber. Air surrounding the flue pipe gets heated up by natural convection. Thermal analysis of cardamom curing chamber by the investigator show that flue pipe heat exchanger used in the curing chamber operates at very low efficiency of the order of 8% main reason being low heat transfer coefficient for gaseous fluid. The present method is very slow also taking around 24-30 hrs to reduce moisture content of cardamom from initial value of 80% (w.b.) to final value of 10% (w.b.).

Under DST funded project TERI has developed an energy efficient cabinet tray dryer for cardamom, which was field tested during last cardamom curing season at Dymock estate of M/s. Harissons Malayalam Ltd., Vandiperiyar. The heart of the system is compact, still easy to fabricate, plate-fin type cross flow heat exchanger operating at high effectiveness of the order of 0.7-0.8. The trial runs indicated that drying can be achieved within 15 hrs with combined furnace and heat exchanger efficiency of the order of 40-50%.

Fuel used for cardamom curing is firewood which is grown on captive forests. Present fuel consumption of wood to produce one kg of cured cardamom is around 3-4 kg. Planters are now facing acute shortage of firewood due to fast depletion of forest and strict government rules. So there is a need to develop a system to utilise wood in more efficient way. Biomass gasifier based system for cardamom drying eliminates heat exchanger component thus obviously improving the thermal efficiency. Also, gasifier application can be extended for power generation to meet electrical power requirement of curing stores.

In the gasifier system chopped firewood is gasified to obtain producer gas. This combustible gas produced in the gasifier undergoes the process of cleaning and then burned with sufficient amount of excess air in the burner to obtain the required temperature and the resulting hot air-gas mixture can be directly used for drying. Part of the gas can be supplied to diesel genset to replace around 60-70% diesel by operating it on dual fuel mode.

For a typical cardamom curing chamber having capacity to cure 400 kg of fresh cardamom, a sample calculation for determining the wood consumption rate to cure cardamom using gasifier based drying system is given below:

Capacity of curing chamber = 400 kg green cardamom
Initial moisture content (M_I) = 80% (w.b.)
Final moisture content (M_F) = 10% (w.b.)
Drying time (T_d) = 15 hrs
Hot air temperature = 55^oC
Amount of hot air required = 3200 kg/hr

Assuming 90% burner efficiency and accounting for ventilation loss and heat through wall structure, the producer gas requirement for drying will be:

$= 47\ Nm^3/hr$

Electricity requirement = 10 kW

Assuming 0.3 lit/kWh diesel consumption of generator and 65% diesel replacement in dual fuel mode amount of producer gas required for power generation

$= 16\ Nm^3/hr$

Total producer gas requirement = $6.3\ Nm^3/hr$

Specific gasification rate of wood = $2.3\ Nm^3/kg$

Wood consumption rate = 27 kg/hr

Total consumption per patch = 405 kg

Amount of fuel consumed to dry one kg of cardamom = 1.01 kg/kg

Thus using biomass gasifier based drying system specific fuel consumption can be brought down from present level of 3-4 kg to 1.01 kg per kg of green cardamom.

7.2 Objectives

The objective of the project is to design, fabricate, test and demonstrate a complete system for cardamom drying using wood gasifier system to reduce the fuel consumption and drying time.

The work includes the following sub tasks:

(i) Visit to cardamom estates for finalising site, etc.

(ii) Design, fabrication of the main gasifier unit

(iii) Design, fabrication of a cooling-cleaning train for removal of tar and particulates.

(iv) Design, fabrication of burner

(v) Procuring and installing of wood chopping machine of suitable capacity and type.

(vi) Transporting and installing the entire system at curing house in estate in collaboration with UPASI and one of the cardamom growing estate.

(vii) Procurement and installation of diesel generator test

(viii) Trial runs on the system during cardamom harvesting season.

(ix) Analysis of data, modification/improvement of the various components of the system in order to achieve desired performance.

(x) Trial runs on the improved system during next years cardamom harvesting season.

(xi) Analysis of data collected and preparation of drawings and final report.

7.3 Technical programme and manner of implementation

The technical programme and manner of implementation of the different phases involved are shown in the bar chart.

Time Frame and Work Schedule

Months

S.No		1	2	3	4	5	6	7	8	9	10	11	12
1.	Estate visit,site finalisation	<--	->										
2.	Design, fabrication of main gasifier		<--	-----	->								
3.	Design, fabrication of cooling train			<----	--->								
4.	Design, fabrication of burner				<-	--->							
5.	Procuring, installing wood chopper					<-	---->						
6.	Transportation, assembly of system at site					<---	---->						
7.	Procurement, installation of diesel genset					<-	---->						
8.	Trial runs on system in cardamom harvesting season							<----	--->				
9.	Data analysis, modifications in the system									<---	-->		
10.	Trial runs in next cardamom curing season										<--	---->	
11.	Preparation of drawing and final report											<--	---->

Note: Cardamom harvesting season starts in September and ends in January.

7.4 Project Budget

A. Salaries and Wages

Professional staff

	1st year	2nd year (amount in rupees.)	3rd year
Fellow - 1 (@ Rs. 8000 per month)	96,000	96,000	96,000
Research Associates - 1 (@ Rs. 6000 per month)	72,000	72,000	72,000
Research Assistants - 1 (@ Rs. 5000 per month)	60,000	60,000	60,000
Technical staff			
Fitters/mechanics - 2 (@ Rs. 3000 per month)	72,000	72,000	72,000
Draftsman - 1 (@ Rs. 3000 per month)	36,000	36,000	36,000
Project Consultants	50,000	50,000	50,000
	3,86,000	3,86,000	3,86,000
	Sub Total		11,58,000

B. Permanent Equipment

	1st year	2nd year	3rd year
High temperature measuring equipment, flow measuring equipment, Gas analyser, etc.	1,50,000	1,00,000	---
	1,50,000	1,00,000	---
	Sub Total		2,50,000

C. Expendable items and Supplies

	1st year	2nd year	3rd year
1. Wood chopping machine, burner, etc.	2,00,000	1,00,000	---
2. Gasifier with cleaning train	1,50,000	---	---

3. Diesel generator set	---	1,00,000	---
4. Blowers, piping, insulation etc.	50,000	50,000	50,000
5. Glassware & chemicals	25,000	25,000	25,000
	4,25,000	2,75,000	75,000
		Sub total	7,75,000

D. Travel and Contingency

Travel	1,00,000	2,00,000	2,00,000
Contingency	75,000	75,000	75,000
	1,75,000	2,75,000	2,75,000
		Sub total	7,25,000
Total	11,36,000	10,36,000	7,36,000
		Sub total	29,08,000
10% overheads			2,90,800
Grand total			31,98,800

PROPOSAL - II

1. Title of the Project : **Development of 100 kW Power Plant Utilising Cashewnut Shell Through Biomass Gasification Route**

2. Name and Address of the Investigator : Dr. V.V.N. Kishore
Senior Fellow
Tata Energy Research Institute
232 Jor Bagh
New Delhi - 110 003.

3. Name of the Institute at which project will be carried out : Tata Energy Research Institute

4. Name(s) of the probable Institution(s) which may be involved in the project : M/s. Achal Industries
Mangalore (Karnataka)
or
Any other Cashew Processing Factory

5. Duration of the Project : 24 months

6. Total amount of assistance sought : Rs. 28.446 lacs

7. Detailed project proposal :

7.1 Preamble

Around 55,000 tonnes of raw cashewnut are processed every year. Standard size bag containing 80 kg of raw cashewnuts gives 35 kg of shell and 23 kg of processed nut. Approximately 50% of shell obtained from raw cashewnut is needed as fuel for providing thermal energy at various stages of cashewnut processing. Thus approximately 12000 ton/year of cashew shell is available in excess in cashew industries which at present is sold outside at a nominal price of Rs. 0.30-0.35 per kg. From rough calculation it is estimated that approximately 275 lakhs units of electricity can be produced per year using this available shell. Utilising this excess shell for power generation can be an attractive option for cashew industries since at present it is sold outside at very nominal price and they have to pay a lot for electricity consumption. Also electricity supply being based on hydro-electric power station is not available through out the day due to load shedding in the summer (February-June) which is the processing season for cashew.

For a typical cashew manufacturing factory sample calculations are given here to work out amount of electricity that can be produced using diesel genset operating on dual fuel mode using diesel and producer gas obtained by gasifying shell. Detailed trial runs for obtaining clean producer gas will have to be undertaken for developing the system.

Raw cashewnut processed = 8 ton/day

Excess shell available = 1.75 ton/day

Calorific value of shell = 5546.6 kcal/kg

Calorific value of Testa/skin = 4676.0 kcal/kg

Gas yield (approximately) = 2.2 Nm^3/kg

Amount of producer gas obtained = 3850 Nm^3/day

Calorific value of producer gas = 1100 Kcal/Nm^3

Assumed thermal efficiency of gasoline engine = 15%

Shaft power available $= \dfrac{0.15 \times 3850 \times 1100}{860}$

= 738.7 kWh/day

~ 740 kWh/day

Total saving on electricity per day, assuming Rs. 2 per unit electricity charges, will be

= 2 x 740

= Rs. 1480 per day

Cost of cashew nut shell = Rs. 0.30 per kg

= 0.30 x 1750

= Rs. 525 per day

The net saving per day will be

= Rs. 955 per day

Total capital cost of the gasifier based power generating system will be around:

Gasifier system for 500 Nm^3/m gas	=	2 lacs
Diesel genset of 75 kW	=	4 lacs
Total system	=	6 lacs

Therefore simple pay back period in terms of operating days with 8 hours shift

$$= \frac{6 \times 10^5}{955}$$

= 628.3 operating days

With approximately 150-160 operating days per year simple pay back period will be around 4 years.

The present proposal aims to develop 100 kW power plant based on gasification of cashew shell in order to meet the electricity demand of cashew processing industry.

7.2 Objectives

The objective of the project is to design, fabricate, install, test and demonstrate a complete 100 kW power plant utilising cashew shell through gasification route. The work includes the following sub tasks:

(i) Visit to various cashew processing factories for getting additional data required and finalisation of site.

(ii) Procuring cashew shell sample for preliminary trials.

(iii) Preliminary runs on the existing TERI gasifier first with cashew shell cake.

(iv) Design and fabrication of main gasifier unit.

(v) Design and fabrication of a cooling-cleaning train for removal of tar and particulates.

(vi) Procuring and installing diesel generator set.

(vii) Assembling of the entire system at site.

(viii) Performance testing of the prototype unit.

(ix) Analysing the data collected and improving/modifying the system to achieve the desired performance.

(x) Preparation of drawing and final report.

7.3 Technical programme and manner of implementation

The technical programme and manner of implementation of the different phases involved are shown in the bar chart.

Time Frame and Work Schedule

Months

S.No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	Finalisation of site for field testing	<--	----	---->																					
2.	Procurement of cashew shell cake for trial runs			<----	----	--->																			
3.	Preliminary runs on existing TERI gasifier						<----	-----	--->																
4.	Design, fabrication of main gasifier unit							<----	----	----	---->														
5.	Design, fabrication of cooling cleaning train								<---	----	-----	---->													
6.	Procuring and installing diesel generator set										<----	-----	-----	--->											
7.	Assembling entire system at site														<----	---->									
8.	Field testing of system for its performance																<---	----	---->						
9.	Improving/modifying the system components																		<----	-----	----	--->			
10.	Analysing data, preparing drawing and final report																						<----	-----	--->

7.4 Project Budget

A. Salaries and Wages

Professional staff

	1st year	2nd year
Fellow - 1 (@ Rs. 8000 per month)	Rs. 96,000	Rs. 96,000
Research Associates - 2 (@ Rs. 6000 per month)	Rs. 1,44,000	Rs. 1,44,000
Research Assistants - 2 (@ Rs. 5000 per month)	Rs. 1,20,000	Rs. 1,20,000

Technical staff

Fitters/mechanics - 2 (@ Rs. 3000 per month)	Rs. 72,000	Rs. 72,000
Draftsman - 1 (@ Rs. 3000 per month)	Rs. 36,000	Rs. 36,000
	Rs. 4,68,000	Rs. 4,68,000
	Sub Total	Rs. 9,36,000

B. Permanent Equipment

High temperature measuring equipment, flow measuring equipment, gas analyser, etc.	Rs. 2,50,000	---
	Rs, 2,50,000	---
	Sub Total	Rs. 2,50,000

C. Expendable items and Supplies

1. Gasifier with cleaning-cooling train	Rs. 1,50,000	---
2. Diesel generator set	Rs. 4,50,000	---
3. Blowers, piping, insulation etc.	Rs. 50,000	1,00,000

4. Heat exchangers, etc.	Rs. 1,00,000	---
5. Glassware & chemicals	Rs. 25,000	Rs. 75,000
	Rs. 7,75,000	Rs. 1,75,000
	Sub total	Rs. 9,50,000

D. Travel and Contingency

Travel	Rs. 1,00,000	Rs. 2,00,000
Contingency	Rs. 75,000	Rs. 75,000
	Rs. 1,75,000	Rs. 2,75,000
	Sub total	Rs. 4,50,000
Total	Rs.16,68,000	Rs. 9,18,000
	Sub total	Rs.25,86,000
10% overheads		Rs. 2,58,600
Grand total		Rs.28,44,600

PROPOSAL - III

1. Title of the Project : **Development of 200 kW Power Plant Utilising Coffee Husk Through Biomass Gasification Route**

2. Name and Address of the Investigator : Dr. V.V.N. Kishore
Senior Fellow
Tata Energy Research Institute
132 Jor Bagh
New Delhi - 110 003.

3. Name of the Institute at which project will be carried out : Tata Energy Research Institute

4. Name(s) of the probable Institution(s) which may be involved in the project : M/s. Mysore Coffee Curing Works, Chikmagalur
or
Any other Coffee Curing Works

5. Duration of the Project : 24 months

6. Total amount of assistance sought : Rs. 31.086 lacs

7. Detailed project proposal :

7.1 Preamble

Coffee is grown in small estates and dried partly at estate level ad remaining at coffee curing works. All the coffee curing works are governed by Coffee Board. A small farmers send their coffee to these curing works and after curing and processing coffee, coffee board sells it. In a single coffee curing works, such as Mysore Coffee Curing Works, Chikamagalur, 8000 tons (4800 tons parchment coffee, 32000 tons cherry coffee) of coffee is processed per year in the plant. Processing of parchment and cherry coffee produces 20% and 50% coffee husk respectively. Husk obtained from parchment coffee can not be briquetted as there is no lignin. Cherry husk can probably be gasified directly. This has to be verified through trial runs. Since large quantity of coffee husk is available at curing works, proper utilisation of it can be done to meet electrical and process heat requirement of the curing works.

Gasification of coffee husk to obtain producer gas and utilising it to run the diesel genset on dual fuel mode to replace approximately 65-70% of diesel consumed can be an attractive alternative since the existing generator set of the curing works can be used which means low initial capital invest. Here the sample calculation is given for a Mysore Coffee Curing Works to show the amount of saving that can be achieved using gasification of coffee husk.

Installed capacity of diesel genset = 200 kW

Amount of diesel consumption (0.3 lit/kWh) = 60 lit/hr

Calorific value of diesel = 10500 kcal/kg

Specific gravity of diesel = 0.85

Calorific value of producer gas obtained from gasifier = 1100 kcal/Nm^3

Amount of producer gas needed to replace 65% of diesel when diesel genset is operated on dual fuel mode will be:

$$= \frac{0.65 \times 0.85 \times 60 \times 10500}{1100} = 316.4 \text{ Nm}^3\text{/hr}$$

Gas yield = 2.2 Nm^3/kg

Amount of coffee husk required = 143.8 kg/hr

Amount of diesel saving = 0.65 x 60
= 39 litres/hr

Price of diesel = Rs. 5 per lit.

Price of coffee husk = Rs. 0.40 per kg

Net saving due to diesel replacement by producer gas.

= cost of diesel saved - cost of coffee husk

= 14

= 39 x 5 - 143.8 x 0.4

= 137.5 Rs. per hr.

Total operating hours of diesel genset assuming 8 hours per day and 150 working days per year

= 8 x 150

= 1200 hrs/yr

Annual saving = 1200 x 137.5

= Rs. 1,65,000

= Rs. 1.65 lacs

Total approximate capital investment on gasifier system with gas production rate of 350 Nm^3/hr is

Cost of gasifier = Rs. 40,000

Cost of related systems = Rs. 1,20,000

Total cost = Rs. 1,60,000

= Rs. 1.6 lacs

Therefore the simple payback period works out to be about 1 years. The present proposal aims to develop a complete system for utilisation of coffee husk through the briquetting and gasification scheme in order to meet the electricity demand of coffee curing works.

7.2 Objectives

The objective of the project is to design, fabricate, install, test and demonstrate a complete 200 kW power plant utilising coffee husk through briquetting and gasification route. The work includes the following sub tasks:

(i) Visit to various coffee curing works for getting additional data required, finalisation of site.

(ii) Procuring coffee husk sample for preliminary trials.

(iii) Preliminary runs on the existing TERI gasifier first with loose coffee husk and if required in briquetted form.

(iv) Design and fabrication of main gasifier unit.

(v) Design and fabrication of a cooling-cleaning train for removal of tar and particulates.

(vi) Procuring and installing diesel generator set.

(vii) Procuring and installing a briquetting machine of suitable capacity and type.

(viii) Assembling of the entire system at site.

(ix) Performance testing of the prototype unit.

(x) Analysing the data collected and improving/modifying the system to achieve the desired performance.

(xi) Preparation of drawing and final report.

7.3 Technical programme and manner of implementation

The technical programme and manner of implementation of the different phases involved are shown in the bar chart.

Time Frame and Work Schedule

S.No		Months																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	Finalisation of site for field testing	<--	----	---->																					
2.	Procurement of coffee husk waste for trial runs			<----	----	--->																			
3.	Preliminary runs on existing TERI gasifier						<----	-----	--->																
4.	Design, fabrication of main gasifier unit							<----	----	----	---->														
5.	Design, fabrication of cooling cleaning train								<---	----	-----	---->													
6.	Procuring and installing diesel generator set										<----	-----	-----	--->											
7.	Procuring and installing briquetting machines										<----	-----	-----	--->											
8.	Assembling entire system at site														<----	---->									
9.	Field testing of system for its performance																<---	----	---->						
10.	Improving/modifying the system components																		<----	-----	----	--->			
11.	Analysing data, preparing drawing and final report																						<----	-----	--->

7.4 Project Budget

A. Salaries and Wages

Professional staff

	1st year	2nd year
Fellow - 1 (@ Rs. 8000 per month)	Rs. 96,000	Rs. 96,000
Research Associates - 2 (@ Rs. 6000 per month)	Rs. 1,44,000	Rs. 1,44,000
Research Assistants - 2 (@ Rs. 5000 per month)	Rs. 1,20,000	Rs. 1,20,000
Technical staff		
Fitters/mechanics - 2 (@ Rs. 3000 per month)	Rs. 72,000	Rs. 72,000
Draftsman - 1 (@ Rs. 3000 per month)	Rs. 36,000	Rs. 36,000
	-------------	-------------
	Rs. 4,68,000	Rs. 4,68,000
	Sub Total	Rs. 9,36,000

B. Permanent Equipment

High temperature measuring equipment, flow measuring equipment, Gas analyser, etc.	Rs. 2,50,000	---
	------------	------------
	Rs, 2,50,000	---
	Sub Total	Rs. 2,50,000

C. Expendable items and Supplies

1. Briquetting plant	Rs. 2,50,000	---
2. Gasifier with cleaning-cooling train	Rs. 2,00,000	---
3. Diesel generator set	Rs. 5,00,000	---

4. Blowers, piping, insulation etc.	Rs. 50,000	1,00,000
5. Glassware & chemicals	Rs. 25,000	Rs. 75,000
	Rs.10,25,000	Rs. 1,75,000
	Sub total	Rs.13,00,000

D. Travel and Contingency

Travel	Rs. 1,00,000	Rs. 2,00,000
Contingency	Rs. 75,000	Rs. 75,000
	Rs. 1,75,000	Rs. 2,75,000
	Sub total	Rs. 4,50,000
Total	Rs.19,08,000	Rs. 9,18,000
	Sub total	Rs.28,26,000
10% overheads		Rs. 2,82,600
Grand total		Rs.31,08,600

PROPOSAL - IV

1. Title of the Project : **Design, Fabrication and Field Testing of Gasifier based Coffee Roasting System**

2. Name and Address of the Investigator : Dr. V.V.N. Kishore
Senior Fellow
Tata Energy Research Institute
232 Jor Bagh
New Delhi - 110 003.

3. Name of the Institute at which project will be carried out : Tata Energy Research Institute

4. Name(s) of the probable Institution(s) which may be involved in the project : M/s. Jayanthi Coffee Works
Chikmagalur (Karnataka State)
or
Any other Coffee Roasting Unit

5. Duration of the Project : 24 months

6. Total amount of assistance sought : Rs. 21.56 lacs

7. Detailed project proposal :

7.1 Preamble

In order to obtain coffee in the final usable form the dried coffee beans undergoes roasting operation. Generally kerosene or high speed diesel (HSD) is used as fuel for coffee roasting. Approximately 25 kg/week, 1 ton/day and 30 ton/day coffee is roasted in small, medium and large coffee roasting factories respectively. In order to roast 75 kg of green coffee beans approximately 4 litres of HSD is consumed. Temperature in the roaster is maintained at around $400^{o}C$. Coffee roasting units such as Jayanthi Coffee Works, Chikmagalur showed interest in developing alternative roasting unit that will result in substantial fuel oil savings.

Gasifier can be used to obtain producer gas through gasification of coffee husk. This gas after thorough cleaning operation can be burned in a burner and used to maintain 400°C temperature during roasting operation, thus saving large quantity of HSD prices of which are rising sharply due to its severe shortage.

Sample calculation for a medium scale roasting unit is done here to compare cost of roasting per kg of green coffee.

$$\text{Amount of HSD required} = \frac{4}{75}$$

= 0.053 lit kg of green coffee)

Fuel cost of roasting operation using HSD = Rs. 0.265 per kg.

Calorific value of HSD = 10500 kcal/kg

Calorific value of producer gas = 1100 kcal/Nm^3

Specific gravity of HSD = 0.85

Amount of producer gas required assuming same burner efficiency in both cases

$$= \frac{0.85 \times 0.053 \times 10500}{1100}$$

= 0.43 Nm^3/kg of green coffee

Amount of coffee husk consumed to roast one kg of green coffee with gas yield of 2.2 Nm^3/kg

$$= \frac{0.43}{2.2}$$

= 0.2 kg/kg

Cost of coffee husk = Rs. 0.40 per kg

Fuel cost of roasting operation using gasifier

= 0.2 x 0.4

= Rs. 0.08 per kg

Thus fuel cost can be brought down to one third of present value of using coffee husk waste for roasting coffee instead of costlier high speed diesel through gasification route resulting in substantial saving of foreign currency. The gasifier being a renewable energy equipment, is eligible for 100% depreciation in the first year and hence the payback period would be even less. The present proposal aims to develop a complete system for utilisation of coffee husk waste through the briquetting and gasification system for roasting coffee in order to save fuel oil substantially.

7.2 Objectives

The objective of the project is to design, fabricate, install, test and demonstrate a complete system for utilisation of coffee husk waste through a process of briquetting and gasification to replace a significant quantity of HSD by producer gas. The work includes the following sub tasks:

(i) Visit to various coffee roasting unit to finalise site and collection of additional data required.

(ii) Procurement of coffee husk waste for trial runs as gasifier fuel.

(iii) Preliminary runs on the existing TERI gasifier with coffee husk in loose form or if required in briquetted form.

(iv) Design and fabrication of the main gasifier unit

(v) Design and fabrication of a cooling-cleaning train for removal of tar and particulates.

(vi) Design and fabrication of suitable burners for producer gas.

(vii) Procuring and installing a briquetting machine of suitable capacity and type.

(viii) Assembling the entire system at one of the selected coffee roasting unit.

(ix) Field testing of the prototype unit for its performance.

(x) Improving/modifying the various components of the system in order to achieve desired performance.

(xi) Analysis of datas, preparation of drawings and final reports.

7.3 Technical programme and manner of implementation

The technical programme and manner of implementation of the different phases involved are shown in the bar chart.

Time Frame and Work Schedule

S.No		Months																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	Finalisation of site for field testing	<--	----	---->																					
2.	Procurement of coffee husk waste for trial runs	<--	----	-----	--->																				
3.	Preliminary runs on existing TERI gasifier					<---	-----	---->																	
4.	Design, fabrication of main gasifier unit							<----	----	--->															
5.	Design, fabrication of cooling cleaning train								<---	----	---->														
6.	Design and fabrication of burners for producer gas									<---	-----	---->													
7.	Procuring and installing briquetting machines										<----	---->													
8.	Assembling entire system at site												<----	----	---->										
9.	Field testing of system for its performance														<----	-----	----	----	---->						
10.	Improving/modifying the system components																			<----	----	-----	--->		
11.	Analysing data, preparing drawing and final report																						<---	-----	--->

7.4 Project Budget

A. Salaries and Wages

Professional staff

	1st year	2nd year
Fellow - 1 (@ Rs. 8000 per month)	Rs. 96,000	Rs. 96,000
Research Associates - 2 (@ Rs. 6000 per month)	Rs. 1,44,000	Rs. 1,44,000
Research Assistants - 1 (@ Rs. 5000 per month)	Rs. 60,000	Rs. 60,000
Technical staff		
Fitters/mechanics - 2 (@ Rs. 3000 per month)	Rs. 72,000	Rs. 72,000
Draftsman - 1 (@ Rs. 3000 per month)	Rs. 36,000	Rs. 36,000
	Rs. 4,08,000	Rs. 4,08,000
	Sub Total	Rs. 8,16,000

B. Permanent Equipment

High temperature measuring equipment, flow measuring equipment, Gas analyser, etc.	Rs. 2,50,000	---
	Rs. 2,50,000	---
	Sub Total	Rs. 2,50,000

C. Expendable items and Supplies

1. Gasifier with cleaning train	Rs. 1,00,000	---
2. Briquetting plant	Rs. 1,00,000	---
3. Burner	Rs. 50,000	---

4. Blowers, piping, insulation etc.	Rs. 50,000	50,000
5. Glassware & chemicals	Rs. 25,000	Rs. 75,000
	Rs. 3,25,000	Rs. 1,25,000
	Sub total	Rs. 4,50,000

D. Travel and Contingency

Travel	Rs. 1,00,000	Rs. 2,00,000
Contingency	Rs. 75,000	Rs. 75,000
	Rs. 1,75,000	Rs. 2,75,000
	Sub total	Rs. 4,50,000
Total	Rs.11,58,000	Rs. 8,08,000
	Sub total	Rs.19,60,000
10% overheads		Rs. 1,96,000
Grand total		Rs.21,56,000

PROPOSAL - V

1. Title of the Project : **Design, Fabrication and Testing of a Complete Tea Drying System using Biomass Gasifier**

2. Name and Address of the Investigator : Dr. V.V.N. Kishore
Senior Fellow
Tata Energy Research Institute
232 Jor Bagh
New Delhi - 110 003.

3. Name of the Institute at which project will be carried out : Tata Energy Research Institute

4. Name(s) of the probable Institution(s) which may be involved in the project : M/s. Tata Tea Ltd.
Munnar (Kerala)
or
Any other Tea Factory

5. Duration of the Project : 24 months

6. Total amount of assistance sought : Rs. 37.521 Lacs

7. Detailed project proposal :

7.1 Preamble

India is the largest producer of tea in the world accounting for about 28% of world production. Currently Indian tea industry is facing problems in keeping the cost of production of tea lower compared to other competitors like Sri Lanka. Though the performance of the tea dryer has considerably improved due to technological innovations, such as fluidised bed dryers, there has not been a significant improvement in the efficiency of the air heater. By introducing a gasifier system for producing tea, the cost of production can be drastically reduced as the heat exchanger is eliminated from the system. Producer gas obtained from the gasifier after thorough cleaning can be burned with sufficient excess air and the resulting hot gases can be directly used for drying. Design of the gasifier for continuous operation, burner design and complete cleaning of gas (because tar particulates in the producer gas may affect the quality of the tea) are the major problem area which are to be dealt with during the course of the study. Following calculation give approximate idea of specific fuel consumption values.

Dryer capacity = 300 kg of made tea/hr

Hot air flow (120°C) = 11,400 kg/hr

Amount of gas required to heat air from 20°C to 120°C assuming 90% burner efficiency will be:

= 275 Nm^3/hr

Specific gasification rate of wood = 2.3 Nm^3hr

Wood consumption rate = 120 kg/hr

Amount of wood required to produce one kg of made tea

= 0.4 kg/hg

Thus the fuel wood consumption rate can be brought down to half (from the present value of 0.9 kg/kg of made tea) by the use of gasifier based drying system. Also since the power-to-heat ratio for tea drying process is around 0.56 cogeneration system using diesel engines for power and process heat generation will be suitable for tea industry. This will make the system more efficient and thus can result in substantial reduction in cost of production of tea. This can be tried in the second phase of the project. The present project aims at developing complete tea drying system using biomass gasification system in order to reduce specific fuel consumption of tea drying process, thus saving significant quality of fuelwood.

7.2 Objectives

The objective of the project is to design, fabricate, install, test and demonstrate a complete tea drying system using biomass gasifier. The work includes the following. sub tasks:

(i) Visit to various tea estates for acquiring additional data required and finalisation of site.

(ii) Design and fabrication of main gasifier unit.

(iii) Design and fabrication of a cooling-cleaning train for removal of tar and particulates.

(iv) Design and fabrication of burner suitable for producer gas.

(v) Procuring and installing wood chopper of suitable capacity and type.

(vi) Procuring and installing tea dryer of suitable capacity and type.

(vii) Procuring and installing diesel generator set.

(viii) Assembling of the entire system at selected site for field testing.

(ix) Preliminary experimental tests on prototype system for evaluating its performance.

(x) Modifying/improving the system in order to achieve desired performance through analysis of collected data.

(xi) Preparation of drawings and final report.

7.3 Technical programme and manner of implementation

The technical programme and manner of implementation of the different phases involved are shown in the bar chart.

7.4 Project Budget

A. Salaries and Wages

Professional staff

	1st year	2nd year
Fellow - 1 (@ Rs. 8000 per month)	Rs. 96,000	Rs. 96,000
Research Associates - 2 (@ Rs. 6000 per month)	Rs. 1,44,000	Rs. 1,44,000
Research Assistants - 2 (@ Rs. 5000 per month)	Rs. 1,20,000	Rs. 1,20,000
Technical staff		
Fitters/mechanics - 2 (@ Rs. 3000 per month)	Rs. 72,000	Rs. 72,000
Draftsman - 1 (@ Rs. 3000 per month)	Rs. 36,000	Rs. 36,000
	Rs. 4,68,000	Rs. 4,68,000
	Sub Total	Rs. 9,36,000

B. Permanent Equipment

High temperature measuring equipment, flow measuring equipment, gas analyser, etc.	Rs. 3,50,000	---
	Rs, 3,50,000	---
	Sub Total	Rs. 3,50,000

C. Expendable items and Supplies

1. Gasifier with cleaning-cooling train	Rs. 2,50,000	---
2. Diesel generator set	Rs. 4,50,000	---
3. Tea dryer system	Rs. 4,00,000	---
3. Blowers, piping, insulation etc.	Rs. 75,000	Rs. 1,00,000
4. Heat exchangers, etc.	Rs. 1,50,000	Rs. 50,000
5. Glassware & chemicals	Rs. 25,000	Rs. 75,000
	Rs.13,50,000	Rs. 2,25,000
	Sub total	Rs.15,75,000

D. Travel and Contingency

Travel	Rs. 1,50,000	Rs. 2,50,000
Contingency	Rs. 75,000	Rs. 75,000
	Rs. 2,25,000	Rs. 3,25,000
	Sub total	Rs. 5,50,000
Total	Rs.23,93,000	Rs.10,18,000
	Sub total	Rs.34,11,000
10% overheads		Rs. 3,41,100
Grand total		Rs.37,52,100

Time Frame and Work Schedule

Months

S.No		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1.	Visit to tea estates for finalization of site	<--	----	-----	--->																				
2.	Design and fabrication of main gasifier system				<---	----	-----	---->																	
3.	Design and fabrication of cooling, cleaning train					<---	-----	---->																	
4.	Design, fabrication of suitable burner for producer gas					<---	-----	---->																	
5.	Procuring and installing wood chopper of suitable capacity								<---	----	---->														
6.	Procuring and installing tea dryer of suitable type							<----	----	----	---->														
7.	Procuring and installing diesel generator set								<---	----	---->														
8.	Assembly of entire system at selected site for field testing											<----	-----	----	---->										
9.	Preliminary experimental test on prototype for its performance evaluation														<----	-----	----	----	---->						
10.	Improving/modifying the system components to achieve desired performance																	<---	-----	-----	----	--->			
11.	Analysing data, preparing drawing and final report																						<----	-----	--->

PROPOSAL - VI

1. Title of the Project : **Development of a briquetting-gasification system for utilization of tobacco waste.**

2. Name and Address of the Investigator : Dr. V.V.N. Kishore
Senior Fellow
Tata Energy Research Institute
232 Jor Bagh
New Delhi - 110 003.

3. Name of the Institute at which project will be carried out : Tata Energy Research Institute

4. Name(s) of the probable Institution(s) which may be involved in the project : M/s. I.T.C. Limited, Bangalore. (Karnataka State)

5. Duration of the Project : 20 months

6. Total amount of assistance sought : Rs. 42.24 lacs

7. Detailed project proposal :

7.1 Preamble

Cigarette making industries requires large quatinty of flue cured virginia tobacco leaves and significant quatity of tobacco waste is produced in the form of dust. For example, I.T.C. Ltd., one of the largest manufacturers of cigarettes requires 60-70 tonnes of tobacco leaves per day at their factory in Bangalore. Approximately 10% of it is prduced as tobacco waste in dust form amounting to 6-7 tonnes per day.

It was found that the tobacco waste can be briquetted without major problem. About 1 ton of tobacco waste was made available by ITC Ltd. and briquetted at briquetting factory at Tumkur near Bangalore. These briquettes after arriving in Delhi were tried for gasification in the down-draft, throatless gasifier developed by TERI in an earlier project and diesel replacement figures of the order of 50% were achieved during initial trial runs.

The Bangalore factory of ITC requires about 25,000-30000 litres of fuel oil per day for processing of 60,000-70,000 kg of tobacco leaves per day. Furnace oil and light diesel oil (LDO) are used for firing the boilers. The following calculations indicate the viability of utilizing tobacco waste for saving fuel oil in substantial quantities.

Tobacco waste produced	6 ton/day
Specific gas production	2.3 Nm^3/kg
Gasifier rating (for a 16 hr/day operation)	860 Nm^3/hr or 9,46,000 kcal/hr or 1100 kW (thermal)
Quantity of fuel oil saved (assuming identical efficiencies for firing with gas and fuel oil)	1700 lit/day or Rs. 8500 per day
Electricity consumption for briquetting (@ 0.1 kWh/kg briquetted material)	600 kWh/day
Annual electricity charges (@ Rs. 1.5 Rs./kWh)	Rs. 1200 per day
Net savings	Rs. 7300 per day
Approximate initial cost	Rs. 20 lakhs
Simple pay back	274 operating days

Assuming 150 operating days every year simple pay back period works out to be about 2 years. The gasifier system being a renewable energy equipment, is eligible for 100% depreciation in the first year and hence the payback period would be even less. Also, the initial cost for subsequent systems installed in other factories would be considerably less and hence the pay back periods would be correspondingly lesser. The present proposal aims to develop a complete system for utilisation of tobacco waste through the briquetting and gasification scheme in order to save fuel oil substantially.

7.2 Objectives

The objective of the project is to design, fabricate, install, test and demonstrate a complete system for utilisation of tobacco waste through a process of briquetting and gasification to replace a significant quantity of fuel oil by producer gas. The work includes the following sub tasks:

(i) Preliminary runs on the existing TERI gasifier with briquetted tobacco waste.

(ii) Design and fabrication of the main gasifier unit complete with ash removal system, biomass feeding system, etc..

(iii) Design and fabrication of a cooling-cleaning train for removal of tar and particulates.

(iv) Design and fabrication of a retrofit system for the existing oil fired boiler, consisting of suitable burners for producer gas.

(v) Procuring and installing a briquetting machine of suitable capacity and type.

(vi) Assemble the entire system at the Bangalore factory of ITC Ltd. and test the performance.

(vii) Improve/modify components of the system in order to achieve the desired performance.

7.3 Technical programme and manner of implementation

The technical programme and manner of implementation of the different phases involved are shown in the bar chart.

Time Frame and Work Schedule

Months

S.No		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.	Preliminary experimentation																				
2.	Detailed engineering of the system including design of various components, preparation of drawings, selection of equipment, selection of suppliers/fabricators, civil and electrical works, area requirements etc.		<---	-----	----	----	-----	---->													
3.	Fabrication/procurement of different items				<---	----	-----	-----	----	----	-----	-----	---->								
4.	Erection and commissioning of the system at the plant site													<---	-----	-----	--->				
5.	Performance testing, collection of data and modification/ improvements in the system if necessary																	<---	-----	-----	--->

7.4 Project Budget

A. Salaries and Wages

Professional staff

	1st year	2nd year (8 months)
Fellow - 1 (@ Rs. 8000 per month)	Rs. 96,000	Rs. 64,000
Research Associates - 2 (@ Rs. 6000 per month)	Rs. 1,44,000	Rs. 96,000
Research Assistants - 2 (@ Rs. 5000 per month)	Rs. 1,20,000	Rs. 80,000
Technical staff		
Fitters/mechanics - 3 (@ Rs. 3000 per month)	Rs. 1,08,000	Rs. 72,000
Draftsman - 1 (@ Rs. 3000 per month)	Rs. 36,000	Rs. 24,000
Project Consultants	Rs. 50,000	Rs. 50,000
	Rs. 5,54,000	Rs. 3,86,000
	Sub Total	Rs. 9,40,000

B. Permanent Equipment

High temperature measuring equipment, flow measuring equipment, Gas analyser, etc.	Rs. 2,50,000	---
	Sub Total	Rs. 2,50,000

C. Expendable items and Supplies

1. Briquetting plant, heat exchanger, etc.	Rs.10,50,000	---
2. Gasifier with cleaning train	Rs. 5,00,000	---
3. Boiler retrofitting	Rs. 1,00,000	---